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Use of male-sterility for increasing the population tolerance of corn (Zea mays L)

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USE OF MALE-STERILITY FOR INCREASING THE POPULATION TOLERANCE OF CORN (ZEA MAYS L.)

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INTRODUCTION

Population density, whether operating directly on the corn plant or indirectly on biotic factors associated with plant density, is one of the most important elements in the biotic environment of a crop. It is known that greater than optimum populations elicit diverse responses by corn plants, both individually and collectively. Overcrowding, as well as undercrowding, may be a production hazard with the adverse effects of overcrowding usually reflected as increased barrenness. Research into the factors affecting barrenness have lead to a basic understanding of certain ecological principles; unfortunately, even with extensive research on plant densities, the physiological determinates of barrenness with increasing population densities remain somewhat obscure.

Male-sterility is one factor affecting the rate of barrenness in a given genotype. Cytoplasmic male-sterility has been utilized most extensively in hybrid seed corn production to eliminate detasseling. Recently, interest has been generated in cytoplasmic effects *per se*, especially under stress conditions of high plant populations, moisture deficits, and low soil productivity. If cytoplasmic effects on population tolerance do in reality exist, incorporation into production schemes, via breeding techniques or through blends of the fertile and sterile counterparts, would be quite easily accomplished.

The purpose of this investigation was to further elicit some of the effects of cytoplasmic male-sterility had on the performance of several single-cross corn hybrids under stress conditions of above optimum plant densities. To achieve this purpose, the following objectives were proposed:

1. To investigate the effect of cytoplasmic male-sterility on the yield and barrenness of several diverse genotypes at high plant densities.

2. To investigate the effect of cytoplasmic male-sterility on the selected plant attributes, ear weight, silking date, rate of silking, plant height, shelling percentage, harvest moisture, 100 seed weight, plant lodging, leaf area, and grain per unit leaf area.

LITERATURE REVIEW

Within the past 10 years, technology has increased corn (Zea mays L.) yields markedly, primarily due to the accelerated use of fertilizers, hybrid seed corn, and ever higher plant densities. The associated increase in inter- and intra-plant competition has brought into wide use the term "tolerance" to describe a hybrid's capability of withstanding higher plant densities within the corn community. A community always has an ecological maximum limit of tolerance which varies with the genetic constitution of the community. This so called "Law of Tolerance" professed by Huber (1961) applies to corn plant densities.

Increased competition for light, water, and nutrients exist as plant densities are increased. One of the most potent of these external forces is the presence of competing neighbors which may reduce a plant to diminutive size. The importance of population density as a biotic entity hardly began to be appreciated until the early 1940's even though the first recorded population experiments were conducted as early as 1889 (Morrow and Hunt, 1891). The role of plant population in corn production was quite comprehensively reviewed by Dungan et al. (1958). Major emphasis will be placed on papers published following this review.

Increasing plant population is known to elicit diverse responses by a corn community. Examination of yield components, ears per plant or per 100 plants, weight per ear, and weight per kernel, revealed that ears per 100 plants is the major factor and ear weight a lesser factor contributing to reduced yields at high plant densities (Lang et al., 1956; Dungan et al., 1958; Zuber et al., 1960; Hinkle and Garrett, 1961; Colville, 1962; Woolley et al., 1962; Stinson and Moss, 1960; Schwanke, 1965; Cardwell, 1967).

Increasing barrenness or reduced number of ears per plant in southern prolific genotypes with increasing plant population led to the "optimum plant population" concept. Optimum planting rates is a recognition of the principle set forth by Warren (1963) in which he states that, "Competition dictates that grain yield follows a curvilinear function as stands increase whereas ear weights follow a negative linear function". Optimum population has been found to vary depending on climatic conditions (Rossman and Cook, 1966) and locations (Stringfield, 1962).

Much of the early work on corn planting rates and patterns were summarized by Richey (1933) in which he concluded that the optimum stand of corn is higher as one proceeds from genetically larger to smaller plants, from lower to higher moisture, and from lower to higher soil productivity. Early researchers found approximately 0.5 pound ears to be associated with maximum yields and thereby utilized ear weights to determine the optimum planting rate (Stringfield and Thatcher, 1947; Dungan et al., 1958).

A major factor influencing plant barrenness and optimum seeding rates for a particular crop is its genotype (Lang et al., 1956; Dungan et al., 1958; Stinson and Moss, 1960; Woolley et al., 1962; Zieserl et al., 1963; Schwanke, 1965; Early et al., 1966, 1967).

Genotypic differences in tolerance to plant densities were first noted in comparisons of open-pollinated with hybrid corn (Springfield and Thatcher, 1947). Rossman (1955) noted that double-cross hybrids exhibited diverse responses to plant densities and that genotypes productive at low populations seemed to be productive at high populations also. Marked differential responses of single-crosses and inbreds to population levels with respect to stalk barrenness were noted by Sass and Loeffel (1959). Giesbrecht (1969) concluded that later maturing, taller hybrids were adapted better to competition at high populations that the earlier hybrids.

Genotypic differences in tolerance to varying population levels of the single-cross cornbelt hybrids Wf9 x C103, Hy2 x Oh7, and Hy2 x Oh41 are well documented (Reichert et al., 1958; Lang et al., 1956; Woolley et al., 1962; Zieserl et al., 1963; Schwanke, 1965; Early et al., 1966, 1967). Lang et al. (1956) found Wf9 x C103 to maximize its yield around 12,000 plants per acre. Raising the population to 24,000 plants per acre increased plant barrenness from 13% for Hy2 x Oh7 to 32% for Wf9 x C103. Similar results were reported by Zieserl et al. (1963). Woolley et al. (1962) found a linear increase in barrenness for six single-crosses as populations increased. Schwanke (1965) categorized 26 genotypes into population tolerant or population intolerant classes on yielding ability at high population densities and found reduced stalk barrenness and larger ear weights to be associated with the tolerant genotypes.

Southern prolific genotypes, however, exhibit little, if any, true plant barrenness unless extreme population stress is applied (Bauman, 1959; Zuber et al., 1960; Josephson, 1961; Hinkle and Garrett, 1961; Prine and Schroder, 1964). Population pressures are expressed as adjustments in the number of ears per stalk with but slight ear weight changes (Zuber et al., 1960; Hinkle and Garrett, 1961). The capacity of prolific hybrids to produce one good ear on each stalk at high rates of planting appeared to Josephson (1961) to be the greatest advantage of prolific hybrids. Bauman (1959) found 162 prolific hybrids to average 1.10 ears per plant at 22,000 plants per acre whereas 173 single-ear hybrids produced an average of only 0.90 ears per plant at 18,000 plants per acre.

Collins et al. (1965) compared 36 single-cross cornbelt hybrids involving one-eared and two-eared inbred lines across four planting rates. He found two-ear-type hybrids to yield consistently more due to their capacity to adjust to environmental fluctuations by changing the number of ears produced. Estimates of maximum planting rates for optimum yields indicated that crosses involving two-eared inbreds may perform better under higher plant densities than one-eared types. Russell (1968) reported that the two-eared three-way crosses had higher optimum plant densities (58,100 plants per hectare) whereas the highest yields of the one-eared crosses were at a lower population (38,700 plants per hectare). Reduced stalk barrenness (fourfold) was attributed with the yield advantage of the two-eared types at 58,100 plants per hectare. Russell (1968) concluded that the two-eared lines' advantage lies in resistance to barrenness exhibited at higher stand levels and not in the production of second ears. Collins et al. (1965) and Russell (1968) substantiated the findings of southern workers (Bauman, 1959; Josephson, 1961; Zuber et al., 1960) on prolific genotypes with semiprolific cornbelt genotypes.

In addition to the genotype, several other environmental and physiological factors are associated with increased plant barrenness, reduced ear weights, and increased plant lodging with increased population stresses. Light, mineral nutrients, moisture, plant patterns, plant date, and canopy shape are a few such factors.

Barrenness is a manifestation of an individual plant response to a given set of environmental conditions. Light is considered by many to be the environmental factor most limiting yields with increased stand levels (Prine, 1961, 1965; Knipmeyer et al., 1962; Stinson and Moss, 1960; Prine and Schroder, 1964; Early et al., 1966, 1967; Colville, 1968). Stinson and Moss (1960) testing six population tolerant hybrids and five population intolerant hybrids for their response to an artificial shade environment found tolerant hybrids, as a group, yielded significantly more grain with reduced light than the intolerant group. Plant barrenness contributed more to the differential yield response of the intolerant than tolerant of shade. Intolerant hybrids required light reduction of 80% or greater to induce barrenness whereas tolerant hybrids required 90% shading (Reichert et al., 1958; Early, 1966).

Light distribution at silking can be an important factor. Grain yields per hectare were significantly reduced when 75 to 100% of solar energy available at silk emergence to leaves located below the ear was intercepted by black polyethylene paper; however, 25 to 50% light restriction had little, if any, effect on grain yields (Schmidt and Colville, 1967). Shading experiments and competitive self shading resulting from high populations have been shown to elicit similar responses (Moss and Stinson, 1961).

Soil productivity, the level of mineral nutrients, has long been known as a major factor affecting population induced barrenness (Dungan et al., 1958; Lang et al., 1956; Hinkle and Garrett, 1961; Berger et al., 1957; Nunez and Kamprath, 1969). Dungan et al. (1958) reviewed the early literature on the effect of plant population and soil productivity. Lang et al. (1956) reported that an increase in the productivity of the soil at any population rate increased the grain produced per plant and tended to be more pronounced as plants per acre increased up to 20,000 due to reduced barrenness at the higher fertility levels. He concluded, however, that population level was a more important factor in determining barrenness than was the nitrogen level or hybrid. In general, as the fertility status is improved, the plant density required to elicit maximum yield by an annual crop is increased. Conversely, as the plant density is increased, the response to an added nutrient will continue to a higher level of application (Donald, 1963).

Moisture has long been recognized as one of the most important environmental factors affecting plant barrenness. A correlation between stalk barrenness at high populations and drought tolerance was noted by Tatum (1954). Robins and Domingo (1953) and Shaw and Loomis (1950) concluded that moisture stress during the fertilization period reduced grain yields markedly by increasing barrenness. Denmead and Shaw (1960) reported 50% reductions in grain yield from moisture stress applied during the silking period. Dale and Shaw (1965) found optimum planting rates to vary depending on the number of "non-stress days" during a six-week period prior to, and including, three weeks after silking. Genotypic tolerance to moisture stress was demonstrated by Barnes and Woolley (1969). They found two-eared hybrids to be more tolerant to an equal moisture stress at the pollination and blister kernel stages than a single-eared variety. These authors all agreed that there is a critical period around flowering in which a lack of moisture exhibits its most detrimental effect via delayed silking, poor pollination, and fertilization.

Interest in the effect of planting patterns on plant barrenness has recently been revived. Early work with planting patterns was reviewed by

Dungan et al. (1958) who found planting patterns to have little effect on plant barrenness. Larger yields obtained from drilled over checked and hill-dropped corn was accounted for by an increased number of ears per 100 plants (Colville, 1962). Recent studies in the cornbelt have shown that for constant plant population, the use of narrow rows has resulted in a higher efficiency of light interception (Denmead et al., 1962; Yao and Shaw, 1964b), water utilization (Yao and Shaw, 1964a), and higher grain yields (Colville and Burnside, 1963; Stickler, 1964; Woolley et al., 1962; Thompson, 1967).

Planting date has an interesting effect on plant barrenness. Late April to early May plantings in the cornbelt have been shown to exhibit yields superior to later plantings (Boone et al., 1966; Hatfield et al., 1965; Pendleton and Egli, 1969; Cardwell, 1967). Grain yield per unit of leaf surface was found to be slightly more efficient for earlier dates of planting (Pendleton and Egli, 1969) with the adverse effects of high plant population accentuated with latter dates of planting. Cardwell (1967) found population intolerant genotypes reacted as population tolerant genotypes and produced higher yields than population tolerant genotypes at the earliest planting date (April 15) but had the lowest yield with latter plantings. High population tolerant hybrids were less affected by planting date. Barrenness and nubbin ear production were reported as the factors resulting in reduced yields of latter plantings with a minimum number of barrens at both normal and high population rates at early dates of planting. Developmental differences attributable to planting date or growing season appears to reflect effects of air temperature, soil moisture, or both (Siemer et al., 1969).

Canopy architecture has recently been suggested as another possible cause of plant barrenness. Utilizing the isogenic lines of C103 x Hy with respect to erect leaves, Pendleton et al. (1968) showed a 40% increase in yield with a 14% decrease in barrenness from erect leaves when compared to its normal counterpart. Mechanical manipulation of the commercial hybrid, Pioneer 3306, into a more upright leaf configuration resulted in grain yields above that produced by the same hybrid in its normal leaf orientation and canopy shape. Canopy architecture affects plant barrenness indirectly through improved light penetration (Williams et al., 1968; Pendleton et al., 1968).

Physiological response by a corn plant to increasing plant populations or differential responses of corn genotypes to factors affecting barrenness have been explained via differential accumulation of dry matter, varying nitrate reductase level, genotypic differences in the photosynthetic rate, the level of plant sugar, rate of ear primordia growth and silk emergence, and the length of the tasseling-silking interval.

Eisele (1935) has shown that the total dry matter produced per plant decreases as plant densities increase. Shading experiments have shown that population tolerant and intolerant hybrids have linear reductions in total dry matter under increasing shade (Reichert et al., 1958; Early et al., 1966; Knipmeyer et al., 1962), however, Wf9 x C103, an intolerant hybrid, decreased dry matter production significantly faster than Hy2 x Oh41, a tolerant hybrid. Carbon dioxide assimilation measurements of tolerant and intolerant single-cross hybrids by Moss and Stinson (1961) showed little differences even though intolerant hybrids were found to yield less.

The ability of plants of the maize mutant, compact, to produce grain under population stress conditions was attributed to the earlier termination of vegetative growth in the compact isoline than in the normal plants (Sowell et al., 1961). Reduced barrenness (62% for the normal versus 5% for the compact isoline at 52,000 plants per acre) was the major plant factor reducing grain yields of the normal isoline. Schwanke (1965), examining 26 genotypes, observed a greater total dry weight for intolerant hybrids as compared to tolerant hybrids at tasseling; however, he was unable to substantiate Sowell's et al. (1961) results. Cardwell (1967) found detasseling or male-sterility to delay or reduce the dry matter percentage for two genotypes.

Hageman and Flesher (1960), Hageman et al. (1961), Knipmeyer et al. (1962), Zieserl and Hageman (1962), and Zieserl et al. (1963) have implicated the level of the enzyme, nitrate reductase, in the differential responses of genotypes to plant populations. The nitrate reductase enzyme is a substrate inducible enzyme which is light dependent (Hageman and Flesher, 1960). Nitrate reductase activity in corn plants has been shown to decrease roughly in proportion to the amount of shading, artificial or competitive self shading, (Hageman and Flesher, 1960; Hageman et al., 1961) with an accompanying increase in nitrate (Knipmeyer et al., 1962; Zieserl et al., 1963). Plant competition was shown to progressively decrease leaf nitrate reductase activity, protein content, and grain yield per plant (Hageman et al., 1961; Zieserl et al., 1963).

Zieserl et al. (1963) and Knipmeyer et al. (1962) found the population tolerant hybrid, Hy2 x Oh7, to have a higher level of nitrate reductase than the population intolerant hybrid, Wf9 x C103. Ranking of 4 single-cross genotypes by Zieserl et al. (1963) according to the nitrate reductase level agreed with the established agronomic yield performance. Zieserl's et al. (1963) work substantiated Knipmeyer's et al. (1962) earlier work in which they concluded that nitrogen metabolism was more adversely affected by decreased light intensity than was carbohydrate metabolism. Cardwell (1967) substantiated these results but also found C103 x Hy, a population intolerant genotype, to be high in nitrate reductase activity. He concluded that a high level of nitrate reductase activity need not necessarily predispose a hybrid to high population tolerance.

Photosynthetic efficiency has been used recently to explain differential genotypic responses to population. Moss et al. (1961) and Baker and Musgrave (1964) found the rate of apparent photosynthesis to be reduced markedly by a moisture shortage (40 to 50% reported by Baker and Musgrave, 1964). Assimilation of barren plants was 55% of normal plants one month after silking (Moss, 1962); however, no differences in the photosynthetic rates were found between tolerant and intolerant genotypes due to shading (Moss and Stinson, 1961). Photosynthetic rates of maize have been shown to differ significantly among races (Duncan and Hesketh, 1968) and among inbreds, hybrids, and open-pollinated varieties (Heichel and Musgrave, 1969).

Stalk sugar concentrations through the critical pollination period have also been shown to vary depending on the inbred used (Van Reen and Singleton, 1952); however, not all sugar differences could be explained by grain yield. Moss and Stinson (1961) and Sowell et al. (1961) have considered stalk sugar as a small factor in distinguishing between population tolerant and intolerant hybrids or as a factor influencing barrenness.

Knipmeyer et al. (1962) agreed that carbohydrate metabolism was not the limiting factor. Cardwell (1967), however, found that as the date of planting was delayed, barrenness increased with an associated decrease in the stalk sugar level; therefore, he concluded that the level of stalk sugar prior to pollination could explain the barrenness observed due to planting date. Williams et al. (1968) suggested that stalk sugar concentration just prior to pollination may even have predictive value relative to fruit set. At this stage, there was a declining sugar percentage with increasing plant density. Since the absolute amount of sugar present is a function of both weight per plant and concentration, the absolute amount of sugar at high plant densities was considerably less. Williams et al. (1968) concluded that such small amounts of sugars and other metabolites are probable causes of observed infertility at high population densities.

Barrenness, associated with increasing plant population, has been associated with delayed silk or ear primordia growth (Sass and Loeffel, 1959; Moss and Stinson, 1961; Collins, 1963; Prine, 1965; Schwanke, 1965; Cardwell, 1967). Sass and Loeffel (1959) suggested that competitive pressure does not produce marked retardations of ear or silk elongations until approximately 68 to 74 days after planting at which time population greatly retards growth of these two plant parts. They concluded that barrenness associated with high plant densities was the result of silks failing to emerge during the pollination period rather than failure of floral organs to develop. Tatum (1954) has stated, "It is but a small step from slow shoot development and delayed silking to barrenness".

Barrenness associated with shading has been shown to be specific on the silking process and not on ear differentiation (Moss and Stinson, 1961); silks generally emerged, but silk growth was usually retarded beyond the shedding of pollen in the intolerant varieties. Schwanke (1965) and Cardwell (1967) found barrenness associated with population intolerant genotypes to be directly related to a greater number of days to reach 75% silked plants. Population intolerant hybrids were shown to silk faster at high populations for earlier planting dates whereas population tolerant hybrids' silking rates were less affected by plant density (Cardwell, 1967). Collins (1963) found the 3-week period just prior to anthesis to be critical for second ear growth and development. Prine (1965) reported the period 2 days before to 3 days after silking to be the critical period when an unfavorable light environment could cause drastic reductions in the number of ears per plant on a semiprolific hybrid. Delayed silking can also affect the receptivity of silks (Peterson, 1942; Lonnquist and Jugenheimer, 1943; Collins, 1963).

The time interval between anthesis and silk emergence increases as population rates increase (Dungan et al., 1958; Sass and Loeffel, 1959; Moss and Stinson, 1961; Woolley et al., 1962; Cardwell, 1967). Dungan et al. (1958) found only a day increase in 50% tasseling and silking for population increases from 8,000 to 20,000 plants per acre. Kohnke and Miles (1951), Lang et al. (1956), and Stringfield (1962), on the other hand, reported an average one-day delay in silking with a population increase of 3,500 to 4,000 kernels per acre. Moss and Stinson (1961) found the time to half-silking in population tolerant hybrids to be delayed 3 days under shade, while the population intolerant hybrids were delayed 5 days when compared to plants grown in full sunlight. Woolley et al. (1962)

found barrenness and a longer silking interval to be closely associated, especially under unfavorable moisture supply or high populations.

One additional factor affecting the level of plant barrenness is male-sterility. Agronomic effects of male-sterility in the form of detasseled plants were reported before the turn of the twentieth century by Schweitzher (1889) and Watson (1893). Watson (1893) reported as much as a 50.2% increase in yield due to detasseling with a 4-year average of 20.2%.

During the early thirties, Leonard and Kiesselbach (1932) concluded from their experiments that an increase grain yield of 1.5% (1.1 bushels per acre) was the result of detasseling but that this difference was not statistically significant. Furthermore, it was concluded that tassel removal when done in such a manner as to avoid leaf mutilation and allow adequate pollination did not materially affect grain yield. Isidoro (1934), working in the Phillipines, observed an 11% additional grain yield from tassel removal. Dungan and Woodworth (1939) and Kiesselbach (1945) substantiated these results. Airy (1955) in a review of several studies found yield responses due to tassel removal to range from a 2% increase in Illinois to a yield decrease of 2% in Nebraska. In all cases, leaf removal reduced yields.

Isidoro (1934) was one of the first researchers to utilize physiological factors in describing the yield response to male-sterility when he suggested that the advantage of tassel removal would probably be most likely to occur on "poor" soil or in dry seasons. Grogan's (1956) experiments, however, were the first comprehensive studies of physiological factors affecting the detasseling yield response in corn. Grogan (1956) studied the detasseling response as affected by climate, soil, and competitive conditions. Yield differences between detasseled and nondetasseled plants under these conditions were associated mainly with a decreased number of barren plants and a small increase in ear size. He concluded that under stress conditions, such as drought, low soil fertility, and/or above optimum plant populations, yield increases associated with detasseling were due to the elimination of competition for nutrients between the ear and tassel. Grogan (1956) predicted that similar results could be expected from cytoplasmic male-sterility.

Cytoplasmic male-sterility was discovered by Rhoades in 1931 in an open-pollinated ear of Peruvian corn. The Rhoades cytoplasmic source was discarded, however, due to its unstable pollen production in favor of the more stable Texas or "T" cytoplasm discovered by Rogers in 1944 (Rogers and Edwardson, 1952). Early work with the "T" cytoplasm was found to have inconsistent increases or decreases in grain yields across several genotypes and environments (Jones and Mangelsdorf, 1951; Rogers and Edwardson, 1952; Rogers, 1954; Jones et al., 1955, 1957; Neal and Strommen, 1956). A significant 2 bushels per acre yield advantage at one Texas location was reported by Rogers and Edwardson (1952) for several single-crosses and two double-crosses under drought conditions. They suggested that the higher yield might be attributed to lower energy expended in sterile tassel production.

Grogan's prediction was substantiated partially by Duvick (1958) and to a greater extent by Chinwuba et al. (1961) and Schwanke (1965). Duvick (1958), studying 6 genotypes at 3 locations (Iowa, Illinois, and Ohio), concluded that sterile genotypes tended to yield more when compared to their normal counterparts as rates of planting increased, at least up to normal optimum planting rates. Barrenness was the plant attribute most closely related to yield. The extent of sterile superiority was markedly affected by the genotype and the physical environment during the growing season.

Chinwuba et al. (1961) showed a 41.2% yield advantage by the male-sterile genotype (detasseled or cytoplasmic male-sterile if one considers losses associated with detasseling and immature pollen production) over the fertile genotype at 27,500 plants per acre and only 17.5% yield advantage at 13,250 plants per acre. Similar results to Chinwuba et al. (1961) were reported by Schwanke (1965) for six genotypes at 32,000 plants per acre. As an average sterile genotypes outyielded their fertile counterparts by 24.4 bushels per acre (24.8%) with a range from a high of 36.4 bushels per acre (54.8%) to a low of 3.4 bushels per acre (5.3%). The yield advantage of steriles was due primarily to reduced barrenness and, to a lesser extent, larger ear weights. The advantage of male-sterility was greater for population intolerant than for population tolerant genotypes as population rates increased. Detasseling or cytoplasmic male-sterility seemed to reduce the detrimental effects of high plant densities, thereby raising the optimum stand level for maximum productivity by a genotype. From their detasseling investigations, Schwanke (1965) and Chinwuba et al. (1961) both concluded that the response to male-sterility seemed to be the elimination of a source of competition for photosynthates between the vegetative and reproductive tissue during tassel and ear emergence. Their conclusions agreed with the earlier work of Duvick (1958) and Grogan (1956).

Sanford et al. (1965) tested the theory of competition between the ear primordia and the tassel on a prolific inbred and hybrid by measuring the seasonal variation in the nitrogen uptake and utilization in corn. They found only slight differences in nitrogen content between fertile and sterile plants in the leaves and stems but found considerably more nitrogen in fertile tassels than sterile tassels before pollen shedding, but subsequent to pollen shedding these differences disappeared. Sanford et al. (1965) suggested that the comparatively fewer ears per plant produced by the fertile versions (0.22 ears per plant for the inbred and 0.42 ears per plant for the hybrid) were due to competition for nitrogen between the ear primordia and the pollen produced by the fertile tassels. Bruce et al. (1966) demonstrated that reduced levels of soil nitrogen more seriously affected ear diameter and length of the fertile strains. However, Cardwell (1967) was unable to find consistent differences in the nitrate reductase activity of fertile and sterile strains.

The increase in radiant flux to the leaves has been suggested as a probable explanation for the yield response from detasseling (Duncan et al., 1967; Hunter et al., 1969). Using the computer, Duncan et al. (1967) estimated yield reductions from tassel shading to range from 4 to 12% with population densities of 10,000 to 30,000 plants per acre. Hunter et al. (1969) found that detasseling resulted in significant yield increases, but detasseling with tassels replaced in the whorl had no yield advantage over the normal hybrid. Furthermore, simulated small tassel size produced by tassel side branch removal resulted in significantly increased grain yields. Duncan et al. (1967) predicted that male-sterile genotypes, due to their smaller tassel, should reduce light interception by tassels also.

The efficiency of water utilization has been advanced as another possible explanation for steriles' yield superiority under low moisture conditions (Bruce et al., 1966, 1969). Studying the effect of a moisture stress during the vegetative, silking, and grain filling periods, Vincent (1968) found the male-steriles of B14 x 577 and 071 x 705 to yield a nonsignificant 5.2 bushels per acre more when averaged over the stress treatments. However, the sterile genotypes required an additional 7 days to reach the arbitrary 75% relative turgidity established as a criterion for a plant moisture stress.

Bruce et al. (1966) found that the male-sterile version consistently yielded more grain than its fertile counterpart primarily due to a greater number of second ears produced. A maximum soil water tension of 6 bars imposed during the fruiting period significantly accentuated the observed differences in ear production, but the 0.3 bar soil moisture tension had little effect. In a later paper, Bruce et al. (1969) concluded from their irrigation experiments that cytoplasmic male-sterile hybrids more efficiently utilized the moisture available in the production of grain and that it was not the response to soil water suction.

Grogan's (1956) prediction, cytoplasmic male-sterility might have a yield advantage under stress conditions, is not entirely substantiated by all researchers. Everett (1960), Johnston and Snyder (1962), and Josephson and Kincer (1962) all concluded that there were no consistent cytoplasmic effects on either the pollen-sterile or restored hybrids; however, specific genomes do vary in response to diverse cytoplasms for agronomic factors such as yield. Noble and Russell (1963) and Marquez-Sanchez (1964) found a reduction in yield (1.1 and 4.3% at 16,000 plants per acre respectively) for restorer hybrids in Texas cytoplasm as compared to the same genotypes in normal cytoplasm. Marquez-Sanchez (1964) found the nonrestored hybrids to average 2.3% higher in grain yield for sterile versions.

A comprehensive testing of 67 three-way crosses of restorer and non-restorer genotypes in both normal and Texas cytoplasm was reported by Duvick (1965). The average yields of the sterile hybrids were the same as their normal cytoplasmic counterparts, but the restored-normal hybrids yielded on the average 2% more than the restored steriles. According to Duvick (1965), this suggested that pollen sterility per se raises yields on the average about 2% but that Texas cytoplasm on the average reduces yield by about 2%. However, Duvick (1965) stresses that in nonrestored hybrids there is a statistically significant interaction between hybrids, environments, and cytoplasms with respect to grain yield. This is in agreement with many other workers (Grogan, 1956; Everett, 1960; Chinwuba et al., 1961; Noble and Russell, 1963; Marquez-Sanchez, 1964).

Cytoplasmic male-sterility has been shown to affect plant characteristics other than yield such as barrenness (Duvick, 1958; Sanford et al., 1965; Bruce et al., 1966; Vincent, 1968; Schwanke, 1965), plant and ear height (Jones, 1950; Neal and Stromman, 1956; Stringfield, 1958; Josephson and Kincer, 1962; Grogan and Sarvella, 1964; Sarvella and Grogan, 1965), number of leaves (Duvick, 1965), silking rate (Jones, 1950; Jones and Mangelsdorf, 1951; Marquez-Sanchez, 1964; Noble and Russell, 1963), the weight of ears (Bruce et al., 1966), and stalk sugar level (Cardwell, 1967). References cited are where marked differences were reported.

Duvick (1958) found that at the Illinois location with 6 genotypes under heat stress all except 1 cytoplasmic male-sterile genotype had a lower percent barrenness than their fertile counterparts. Schwanke's

(1965) data shows marked decreases in percent barren plants by male-sterile genotypes at 32,000 plants per acre. Vincent (1968) showed an average non-significant 6.5% increase in barrenness across 2 genotypes under moisture stress. Cytoplasmic male-steriles' yield advantage was due to a larger number of ears per plant (1.77 compared to 1.36 for the fertile) on a southern prolific genotype, F44 x F6 (Bruce et al., 1966). Josephson and Kincer (1962), however, found no differences in the number of ears per plant.

Cytoplasmic male-sterility has been known to influence plant and ear height most consistently of all factors reportedly affected by sterile cytoplasm. Grogan and Sarvella (1964), Sarvella and Grogan (1965), and Bruce et al. (1966) have shown height in a southern prolific to be reduced mainly due to the internode length above the ear, the length of the tassel culm, and, to a lesser extent, shorter internodes below the ear. Shortening occurred from 10 to 14 days after meiosis up to maturity (Sarvella and Grogan, 1965). Vincent (1968) showed the genotypes 071 x 705 and B14 x 577 to be significantly shorter with some ear height reduction for the sterile versions when compared to their fertile counterparts. The nonsequential shortening of the internodes in the steriles may have arisen from a temporary block or stimulation, depending on the genotype, of the plant hormones regulating cell elongation or cell division (Grogan and Sarvella, 1964; Sarvella and Grogan, 1965).

Leaf number has been shown to be cytoplasmically affected. Texas cytoplasm appears to reduce the number of leaves per plant by 1 to 2% and is evident from the first leaf count (Duvick, 1965). Leaf area index was shown to be slightly less for a male-sterile genotype (4.07 versus 4.23

LAI) when compared to fertile counterpart at 19,360 plants per acre (Bruce et al., 1966).

The ear weight of the second ear was significantly greater for the sterile genotype when compared against its fertile counterpart, however, no consistent differences were found in the first ears (Bruce et al., 1966). Reduced soil water levels more seriously affected ear diameter and length of the fertile strains than sterile strains.

The rate of silking has been shown to occur somewhat faster in some sterile genotypes than in their fertile counterparts (Jones and Mangelsdorf, 1951; Jones, 1950; Marquez-Sanchez, 1964; Noble and Russell, 1963). Jones (1950) and Jones and Mangelsdorf (1951) showed that as an average 0.2 day faster silking rate occurred for the cytoplasmic male-steriles. Marquez-Sanchez (1964) reported 0.6 days earlier silking rate when nonrestored steriles were compared to fertiles; however, Stringfield (1958) failed to establish significant differential cytoplasmic effects on the silking dates. The interval between pollen shedding and silking was reported to be reduced significantly for certain natural restorer lines when tested in sterile type cytoplasm (Noble and Russell, 1963). Vincent (1968) showed a nonsignificant 1.5 days faster silking rate for the sterile genotype, however, he showed a significant genotype by sterility interaction on days to reach 75% silking. Schwanke's (1965) data showed an average of 3.2 days faster silking for 6 sterile genotypes when compared to their fertile counterparts.

Higher sugar percentages for male-sterile genotypes when compared to the fertile genotypes were observed by Cardwell (1967). Cardwell (1967) concluded that male-sterility reduces the plant's respiratory needs thus increasing the stalk sugar level and promoting ear development.

Normal and Texas cytoplasmic hybrids have been compared for several other agronomically important characteristics such as moisture, shelling percentage, stalk and root lodging, tendency to tiller, and resistance to infection with Helminthosporium Turcicum; but no consistent cytoplasmic effects have been reported (Everett, 1960; Josephson and Kincer, 1962; Noble and Russell, 1963; Rogers and Edwardson, 1952; Neal and Strommen, 1956).

As one can see, the literature on the effect of cytoplasmic male-sterility on agronomically important characteristics such as yield is somewhat confusing. A given nonrestored cytoplasmic male-sterile genotype can outyield its fertile counterpart (Duvick, 1958; Chinwuba et al., 1961; Grogan and Sarvella, 1964; Schwanke, 1965; Bruce et al., 1966, 1969), however, comparisons across several genotypes (Everett, 1960; Josephson and Kincer, 1962; Duvick, 1965) often fail to show consistent cytoplasmic effects on plant attributes other than height and pollen shedding. One can conclude from the literature than there is a marked interaction among hybrids, environments, and cytoplasms with the superiority of male-sterile genotypes usually expressed under stress conditions such as above optimum plant populations.

MATERIALS AND METHODS

A series of field plot experiments were conducted during 1967, 1968, and 1969 at the Madrid experimental farm 15 miles southwest of Ames, Iowa, and at the Beach Avenue experimental site in 1968 and 1969. The soil type at Madrid was mainly a Nicolett clay loam with an area of Webster silty clay loam and Harpster loam located mainly in one replication. Average plowlayer fertility was low to medium for nitrogen, very low for phosphorus, and very low to medium for potassium. These soils varied from slightly acid to calcareous with moderate permeability. The soil type for the Beach Avenue site was a Colo silty clay loam underlain with fine sand lenses at depths of 4 to 6 feet. Plowlayer fertility was medium to low for nitrogen, phosphorus, and potassium with a good infiltration rate. The soil pH was slightly acid. Soil topography ranged from 0 to 3% for the Madrid soil while the Beach Avenue soil had no slope.

Each location was fall plowed with most phosphorus and potassium broadcast prior to plowing. Most nitrogen was applied prior to planting, except 100 pounds per acre of nitrogen was sidedressed on both sites in 1968 and on the Beach Avenue site in 1969. Starter fertilizer was applied in 1968 and 1969 at the approximate rate of 15, 30, and 60 pounds of nitrogen, phosphorus, and potassium per acre respectively.

The total amount of fertilizer applied per site was as follows:

Site	Fertilizer in pounds per acre N	P	K
Madrid, 1967			
Block I	150	214	403
Block II	150	29	54
Madrid, 1968			
Block I	315	32	60
Block II	315	200	379
Beach, 1968	190	68	126
Madrid, 1969	235	29	55
Beach, 1969	200	--	--

Experimental treatments for this study consisted of various hybrids, population levels, and the fertile-sterile cytoplasm comparison. Table 1 lists for each environment the populations, hybrids, plot size, and planting date used.

Single-cross hybrids (Zea mays L.) were selected for their response to high plant densities and on the availability of seed for the normal and Texas (N and T) cytoplasms comparison. Schwanke (1965) previously classified the variety B14 x 577 as a population tolerant genotype and the variety 071 x 705 as a population intolerant variety. The varieties PX610, XL-45, SX 29, P3306, and UH 138 were commercial varieties selected as population tolerant hybrids from the 1966 Iowa Corn Yield Test. The remaining genotypes were unclassified as to their population tolerance. Seed was acquired from various sources and represents diverse cornbelt single-cross hybrids. Sterile versions of each variety, to the best of our knowledge, were of the Texas male-sterile cytoplasm (Tcms) with the homozygous recessive gene at the Rf allele. Fertile genotypes were also nonrestorers. Adequate pollen for pollination of the Tcms hybrids was supplied by a mixture of the T and N genotypes in the border rows that divided each treat-

Table 1. Populations, hybrids, plot size, and planting date for Experiments 1-5

	Experiment Number				
Year	1	2	3	4	5
Year	1967	1968	1969	1969	1969
Location	Madrid	Madrid	Madrid	Madrid	Madrid
Population[a]	18,000	17,932	18,259	18,259	17,860
	36,000	35,864	36,417	23,910	35,719
		53,864		29,996	54,014
		71,729		36,417	
				53,906	
Hybrids	071x705[b]	A619xA632[h]	PX610	PX610	XL-45
	P3510[b]	UH 138	XL-45	XL-45	P3306
	B14x577[b]	P3510	B14x577	B14x577	B14x577
	M2036[c]	336x025	A619xA632	A619xA632	P3510
	336x025[b]	P3306[b]	P3510	P3510	
	425x091[b]	B14x577	UH 108		
	544x216[b]	336x029	155x526		
	336x029[b]	SX 29	425x091		
	155x526[b]	PX610	544x216		
	UH 138[d]	XL-45[g]	071x705		
	UH 108[d]				
	SX 63[e]				
	SX 9[e]				
	SX 29[e]				
	PX610[f]				
Plot size					
Length (feet)	30	33.3	33.3	33.3	33.3
Width (rows)	8-12"	6-20"	6-20"	6-20"	6-20"
Planting date	May 8-9	April 29-30	April 29-30	April 29-30	June 17

[a]Plant population in plants per acre.

[b]Seed source Pioneer Hybrid Seed Corn Co., Johnston, Iowa.

[c]Seed source Earl May Seed Co., Shenandoah, Iowa.

[d]Seed source Asgrow Seed Co. (United Hagie), Ames, Iowa.

[e]Seed source Pfister Associated Growers, Aurora, Illinois.

[f]Seed source Northrup King, Minneapolis, Minnesota.

[g]Seed source Dekalb Hybrid Seed Corn Co., Dayton, Iowa.

[h]Seed source Clyde Black and Sons Seed Co., Ames, Iowa.

ment in all experiments. In Experiment 1, the N and T cytoplasmic genotypes were planted side by side; therefore, border row mixtures were not deemed necessary.

At least a normal population (18,000 plants per acre) and high population (36,000 plants per acre) were included in all experiments to investigate the effect Tcms had under the stress condition of high plant densities. Stand levels of 54 and 72,000 plants per acre were included in Experiment 2 to investigate the influence the cytoplasm type had at stand levels considered extremely high. The population levels as shown in Table 1 will be referred to as 18, 24, 30, 36, 54, and 72,000 plants per acre.

A split-split-split randomized complete-block design was utilized in Experiment 1. The 15 hybrids made up the main plot with the type of cytoplasm constituting the subplots. The 2 population levels made up the subsubplots. Since the soil fertility level was generally nonsignificant, the fertility level and blocks were pooled to give 4 replications for each treatment. A split randomized complete-block design was utilized for Experiments 2-5 with the hybrids constituting the main plots. The population level and the cytoplasm type constituted the subplots and were randomized within the main plots. Four replications of each treatment were employed.

Seedbeds were prepared following normal cultural practices common to the central Iowa area. All plots except Experiment 1 were drilled at 20 to 100% over the desired stand level with an Allis Chalmers Model 600 minimum tillage planter modified for experimental plot work. Plots were subsequently thinned to the desired plant density when plants were approximately 8 to 20 inches tall. Interplant spacings were kept as uniform as possible.

Final stand counts were near desired stand levels for 18 thru 30,000 plants per acre, but higher plant densities tended to loose harvestable population, presumably, due to interplant competition, as exemplified in Appendix Table 61. Experiment 1 was planted with a V-belt planter. Plots were planted 10% high for germination losses but were not thinned. Harvest population was counted shortly after mid-silking.

Atrazine and Ramrod herbicides were applied to chemically control weeds; however, a sweep type cultivation was considered necessary for herbicide tolerant weed species in all experiments except Experiment 1. Furthermore, all plots were hand weeded as deemed necessary. Soil insecticide (Bux-ten) was broadcasted on Experiment 1 one week after planting at the rate of 10 pounds per acre. Likewise, Bux-ten was broadcasted over the corn's whorl during the cultivation operation for Experiments 3, 4, and 5 at the rate of 20 pounds per acre to control both the first brood European corn borer and corn rootworm larva. The insecticide, Seven, was sprayed during the early stages of silking to reduce silk feeding by corn rootworm beetles.

Silking dates were determined by randomly selecting 20 consecutive plants of a tagged harvest row and daily or bidaily recording the number of plants silking. The number of silking plants was then plotted versus the calendar date and the 25, 50, and 75% silking dates determined to the nearest ½ day for Experiments 1 and 2 and to the nearest ¼ day for Experiments 3-5. The silking rate was calculated as the difference in days between 25 and 75% silking for Experiments 2-5 and between 50 and 80% silking for Experiment 1.

Leaf area estimates were made on 4 randomly selected plants for 2 replications of Experiment 2 and 4 replications of Experiments 3 and 4. Leaf area was estimated by multiplying the product of the length and width measurements of each leaf by 0.75 and accumulating for an individual plant similar to the method of Montogomery (1911) and McKee (1964). Leaf area measurements were taken 1 to 4 weeks after the 50% silking date; therefore, leaf area among hybrids should be viewed with caution since the stage of maturity (number of lower leaves senescencing) varied with the hybrid.

The harvest date, type of harvest, and harvest plot area are given in Table 2. All plots were harvested following maturity except Experiment 5

Table 2. Harvest date, method, and area for Experiments 1-5

Variable	Experiment Number 1	2	3	4	5
Date	Nov. 3-11	Oct. 1-25	Sept. 19-23	Sept. 19-23	Oct. 20-27
Method	Combine	Combine Hand[1]	Combine Hand[2]	Combine Hand[2]	Hand
Area					
Length	25	26	29	29	29
Rows	5-12"	4-20"	4-20"	4-20"	2-20"
Acre fraction					
Combine	1/348	1/311	1/300	1/300	
Hand		1/1304	1/899	1/899	1/451

[1]Hand harvest area (1-20" row 20 feet long).

[2]Hand harvest area consisted of 1 of the 4-20" rows.

which was harvested approximately 2 weeks after a killing frost. Experiment 1 was mechanically harvested by an Allis Chalmers Model E combine equipped with a small grain-head. Plots were combined, lost ears which were sighted gleaned, total grain sample weighed, and a 2 to 3 pound moisture sample taken. Similar harvest procedure was followed for Experiments 2, 3, and 4 except the combine was equipped with a 4-row 20-inch corn-head; furthermore, part of each plot was hand harvested. Stand counts and the number of ears and nubbins were recorded from the hand harvest area. All subsequent harvest data were calculated from the hand harvest. Lodging notes were taken during the mechanical harvest as a visual rating of the percentage of the plants broken or lodged. Severe wind damage on September 6 caused extensive stalk breakage in 1969. Experiments 2-5 sustained moderate wind damage during the vegetative stage; however, most hybrids had their growing points located at or near the ground level facilitating plant recovery. Unfortunately, some population loss was experienced, but it was considered insignificant.

Plot samples harvested by hand in Experiments 2 and 3 were dried to a constant weight at 160°F, weighed, and the grain yield computed by assuming a bushel of ear corn to weigh 70 pounds. The plot samples from Experiments 4 and 5 were dried to a constant weight at 180°F, weighed, shelled mechanically, and the shelled grain weighed. Moisture samples were likewise dried to a constant weight at 160°F. All grain yields are reported as bushels per acre of number two shelled corn at 15.5% moisture. Combine grain yield will hereafter refer to yield estimates from mechanical harvest while grain yield will refer to hand harvest yield estimates.

Ear weights were calculated by dividing the total plot sample from the hand harvest by the number of ears. One hundred kernels were mechanically counted and weighed for kernel weight and expressed in grams per 100 seed on a dry weight basis. Grain per unit leaf area was expressed in grams per decimeter squared (grams/dm^2) of leaf area.

Barrenness was defined as those harvested plants that did not produce an ear; therefore, barrenness includes those plants that produced a nubbin ear (less than 25% of the cob's surface area covered with kernels). Since high plant populations tended to loose harvest population, as stated previously, percent barrenness is a conservative estimate of the number of barren plants. For Experiment 1, where only a combine grain yield estimate was taken, barrenness was determined by counting the number of ear-bearing stalks per 50 stalks one day prior to harvesting.

Statistical analysis varied with the design employed. Standard analysis of variance as presented by Steel and Torrie (1960) for the designs used (illustrated in Table 3) was performed on all variables measured in

Table 3. Source of variations and the degrees freedom for Experiments 1-5

Source	Expt. 1 d.f.	Source	Expt. 2 d.f.	Expt. 3 d.f.	Expt. 4 d.f.	Expt. 5 d.f.
Blocks	3	Blocks	3	3	3	2
Hybrids (H)	14	Hybrids (H)	9	9	4	3
Error (a)	42	Error (a)	27	27	12	6
Cytoplasm (C)	1	Cytoplasm (C)	3	1	4	2
H x C	14	Population (P)	1	1	1	1
Error (b)	45	C x P	3	1	4	2
		H x C	27	9	16	6
Population (P)	1	H x P	9	9	4	3
H x P	14	H x C x P	27	9	16	6
C x P	1	Error (b)	210	90	135	40
H x C x P	14					
Error (c)	90					

each experiment. The linear and quadratic single degree orthognal comparisons were calculated for the population by cytoplasm and variety by cytoplasm interactions of Experiment 4 since the greatest interest was in these 2 comparisons. Due to the unequal spacing of the population treatments, the linear and quadratic orthognal coefficients were calculated similar to the example presented by Snedecor (1958). The linear and quadratic coefficients used are as follows:

Variable level	Population by cytoplasm Linear	Population by cytoplasm Quadratic	Variety by cytoplasm Linear	Variety by cytoplasm Quadratic
1	-12	262	-2	2
2	-7	-15	-1	-1
3	-2	-186	0	-2
4	3	-251	1	-1
5	18	190	2	2

Homogeneity of error variance was tested using the F test as described by Steel and Torrie (1960) for 2 error mean squares and Bartlett's (1937) test of homogeneity for more than 2 error mean squares. Homogeneity was measured for all plant characteristics on errors (a), (b), and, where applicable, (c). The error variance was found to differ significantly for each error term and for all plant characteristics measured; therefore, since the plot size varied, no attempt was made to compute a combined analysis.

Duncan's new multiple-range test as presented by Duncan (1955) was utilized to establish meaningful difference levels. Since the comparison between the N and T cytoplasms was of major interest, all subsequent tables have the least significant range (LSR) to be significantly different at the 5% level of probability quoted for the N and T cytoplasm comparison only.

In 1968 a row spacing experiment was initiated to investigate the response of extremely high plant densities to narrow row spacings and to further elicit the effect the type of cytoplasm had at various population levels. Methods and material for Experiments 6 and 7 were similar to Experiment 2 while Experiment 8 was handled similar to Experiments 3 and 4. Only where differences between the experiments occurred will the procedure be discussed.

Table 4 lists for each environment the population levels, hybrids, size of the experimental unit, and the planting date used in Experiments 6-8. Stand levels as shown in this table will hereafter be referred to as 15, 18, 22.5, 30, 37.5, 45, and 54,000 plants per acre.

A split-split randomized complete-block design was utilized for all experiments. The main plot for Experiments 6 and 8 was row spacing (10-, 20-, 30-, 40-, and 60-inch rows and 10-, 20-, and 40-inch rows for Experiments 6 and 8 respectively). Hybrids constituted the subplots with the population and cytoplasm completely random within the subplots and making up the sub-subplots. Each treatment was replicated 2 and 3 times for Experiments 6 and 8 respectively. Experiment 7 followed the design of Experiment 6 except hybrids constituted the first split (main plot) while the 2 row spacings (20- and 40-inch rows) constituted the subplots.

Seedbed preparation and planting procedure was similar to Experiments 2-4. The herbicides, Atrazine and Ramrod, were applied to chemically control weeds; however, a sweep type cultivation was deemed necessary on all plots except, of course, the 10-inch rows where plots were hand weeded as

Table 4. Population hybrid, plot size, and planting date for Experiments 6-8

Variable	6	7	8
Year	1968	1968	1969
Location	Beach	Madrid	Madrid
Population[a]	15,487 30,159 44,831	17,932 53,864	14,810 22,216 29,621 37,461 45,302
Hybrids	SX 29 XL-45	A619 x A632 UH 138 P3510 336 x 025 P3306 B14 x 577 336 x 029 SX 29 PX610 XL-45	SX 29 P3306
Plot size			
Length (feet)	33.3	33.3	33.3
Width (rows)	12-10" 6-20" 4-30" 4-40" 3-60"	6-20" 3-40"	12-10" 6-20" 4-40"
Planting date	May 6	April 29-30	May 5

[a]Plant population in plants/acre.

deemed necessary. The insecticide, Seven, was sprayed during the early silking stage to reduce silk feeding by corn rootworm beetles in Experiment 8.

The silking date and rate were determined as presented in the previous section. Leaf area estimates, however, were not taken in Experiments 6-8.

The light flux intercepted at both the ear and ground levels was measured for each treatment of SX 29 in Experiment 6. All readings were taken within plus or minus 2 hours of solar noon on clear days between August 8 and August 30, 1968, with a Weston Illumination Meter. For each treatment, the light flux intercepted was measured as a mean of 10 readings taken every 6 inches perpendicular to the run of the row with 3 replications. Total light flux density at the crop surface was measured prior to and following each measured plot with an average reading utilized. The height of the ear was recorded for each unit measured.

The harvest date, type of harvest, and the harvest plot area are given in Table 5. Harvest procedure was similar to the previous experiments

Table 5. Harvest date, method, and area for Experiments 6-8

Variable	Experiment number		
	6	7	8
Date	Oct. 17-19	Oct. 1-25	Nov. 4-5
Method	Combine	Hand	Hand
Area			
Length (feet)	29	10	29
Width (rows)	8-10" 4-20" 2-30" 2-40" 1-60"	2-20" 1-40"	2-20"
Acre fraction	1/225 or 1/300	1/1304	1/451

(2-5) with grain yield expressed as bushels per acre of number two shelled corn at 15.5% moisture. Likewise, ear weight, kernel weight, and barrenness were determined similar to these experiments.

The standard analysis of variance was performed on all variables measured. The sources of variation and the degrees freedom are presented in Table 6 for each experiment. Duncan's new multiple-range test was employed to determine meaningful differences. Only the least significant range for significance at the 0.5% level of probability for the N and T cytoplasm comparison was quoted in the tables unless otherwise stated.

Table 6. Source of variation and the degrees freedom for Experiments 6-8

Expt. 6		Expt. 8	Expt. 7	
Source	d.f.	d.f.	Source	d.f.
Blocks	1	2	Blocks	3
Row spacing (R)	4	2	Hybrids (H)	9
Error (a)	4	4	Error (a)	27
Hybrids (H)	1	1	Row spacing (R)	1
R x H	4	2	H x R	9
Error (b)	5	6	Error (b)	30
Cytoplasm (C)	1	1	Population (P)	1
Population (P)	2	4	Cytoplasm (C)	1
C x P	2	4	P x C	1
R x C	4	8	H x P	9
R x P	8	2	H x C	9
R x C x P	8	8	H x P x C	9
H x C	1	1	R x P	1
H x P	2	4	R x C	1
H x C x P	2	4	R x P x C	1
R x H x C	4	2	H x R x P	9
R x H x P	8	8	H x R x C	9
R x H x C x P	8	8	H x R x P x C	9
Error (c)	50	108	Error (c)	180

EXPERIMENTAL RESULTS

Cytoplasm by Population Study

Several diverse single-cross hybrids were grown during 1967, 1968, and 1969 at Madrid and Ames, Iowa, at various planting rates as previously described. Yield levels were lower in 1967 than in 1968 and 1969. Growing conditions were somewhat unfavorable in 1967 due to 5.5 inches above average rainfall during June and a moderate moisture stress during the pollination-fertilization period. Average monthly temperatures, however, were 2 to 4 degrees below normal during the growing season. Growing conditions during 1968 and 1969 would be considered favorable to highly favorable. Mean monthly temperatures were average in 1968 except during July when temperatures were 2 to 3 degrees below normal. A slight moisture stress could have occurred during the pollination-fertilization period. Likewise, in 1969 mean monthly temperatures were below average in June and July with above average precipitation during July. In fact, some plots were noted to maintain a wet surface until early to mid-August.

Madrid 1967 (Experiment 1)

Fifteen single-cross hybrids, each with the fertile and sterile counterparts, were planted at a normal plant population (18,000 plants per acre) and a high plant population (36,000 plants per acre) at Madrid, Iowa, in 1967. The following five plant characteristics were measured: combine grain yield, barrenness, kernel weight, mid-silking date, and silking rate. Mean plant response and the analysis of variance for each variable are presented in Appendix Tables 57 and 58 respectively. Experimental results for this experiment should be viewed with caution. Due to the abundance of rainfall during June, 1967, parts of all replications were severely stunted by a water logged soil condition entering extreme variability into the data.

The main effects, hybrids, population levels, and cytoplasm type, were statistically significant for combine grain yield with the hybrid and population highly significant. Male-sterility increased mean combine grain yield by 3.9 bushels per acre for an average 3.5% advantage. Single-cross hybrids varied in their response to male-sterility ranging from a 20.0% increase for 071 x 705 to 14.7% decrease for 336 x 025 which was shown as a highly significant interaction between the hybrid and the cytoplasm. For 11 out of 15 single-cross hybrids used, the sterile genotype yielded greater than its fertile counterpart; however, only 4 sterile genotypes yielded significantly greater than and 2 less than their fertile counterparts when tested by Duncan's multiple-range test (Figure 1).

The combine grain yield for 2 population levels as affected by the type of cytoplasm is shown in Table 7. Combine grain yield as a mean of 15 hybrids was for the sterile genotypes 2.2 and 4.7% higher than the fertile genotypes at 18 and 36,000 plants per acre respectively; however, the cytoplasm by population interaction was nonsignificant. As one might expect from the diversity of the hybrids chosen, a highly significant population by hybrid interaction was obtained.

Differences in grain yield for different population levels are often the result of barrenness. Barrenness was affected by all main effects. Male-sterility reduced the number of barren plants at both population levels, but the response was more pronounced at the high populations (Table 8) leading to a highly significant interaction.

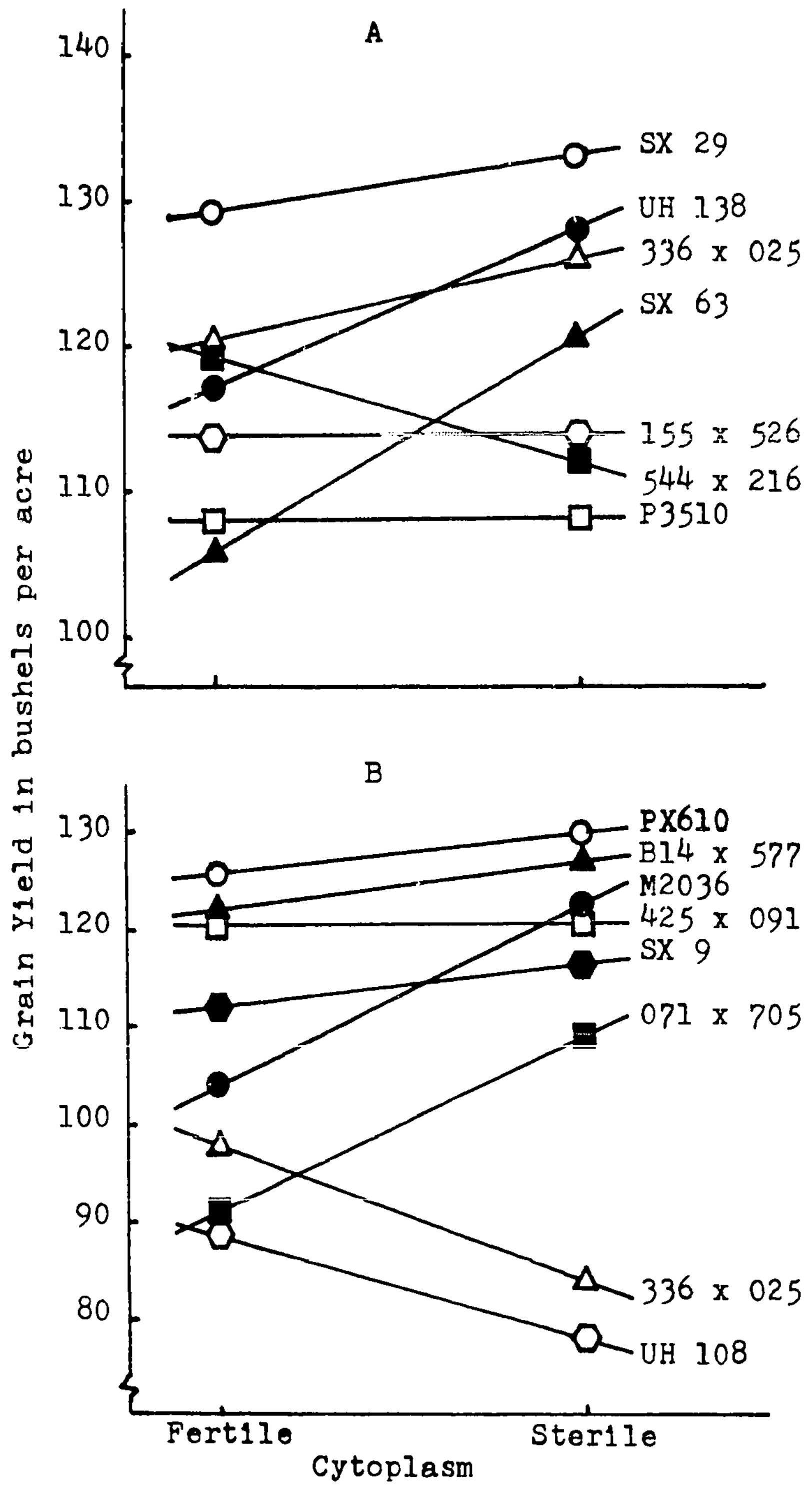

Figure 1. Grain yield for 15 hybrids (A and B) as affected by male-sterility (mean of 2 populations in 1967)

Table 7. Combine grain yield for 15 hybrids at 2 population levels as affected by male-sterility in 1967

Hybrid	Grain yield in bushels per acre			
	18,000[a]		36,000[a]	
	Fertile	Sterile	Fertile	Sterile
071 x 705	98.8[b]	110.8[b]	82.8	107.3
P3510	109.3	108.3	107.3	109.0
B14 x 577	121.5	123.0	121.0	132.5
M2036	103.8	126.8	105.5	118.0
336 x 025	95.5	81.8	102.3	87.0
425 x 091	109.0	122.5	131.5	121.5
544 x 216	115.0	94.3	124.5	132.3
336 x 029	123.0	130.8	118.3	121.3
155 x 526	113.5	119.5	115.3	109.0
UH 138	112.5	115.5	121.5	141.8
UH 108	89.5	65.8	89.0	90.8
SX 63	109.5	120.3	102.5	124.0
SX 9	113.8	114.3	110.3	119.3
SX 29	125.3	138.0	133.0	127.5
PX610	119.5	124.0	131.5	135.8
Mean	110.6	113.0	113.1	118.4

[a]Population in plants/acre.

[b]LSR = 16.4 bu/a.

Male-sterility reduced the number of barren plants for 14 hybrids, 7 significantly. Mean response to the type of cytoplasm was 16.2% versus 8.4% barrenness for the N and T cytoplasms respectively; however, individual hybrids responsed differently to the type of cytoplasm (Table 8) which led to a significant hybrid by cytoplasm interaction.

Kernel weight differed at the 1% probability level for hybrids, population levels and their interaction, hybrid by population. A significant hybrid by cytoplasm interaction also exceeded the 1% probability level. Six hybrids differed significantly; 3 hybrids increased, and 3 hybrids

Table 8. Percent barrenness for 15 hybrids for 2 population levels as affected by male-sterility in 1967

	Barrenness in percent			
	18,000[a]		36,000[a]	
Hybrid	Fertile	Sterile	Fertile	Sterile
071 x 705	12.5[b]	2.5[b]	29.0	17.3
P3510	19.8	5.0	47.0	14.5
B14 x 577	11.3	0.0	21.8	10.5
M2036	12.5	10.3	36.8	15.8
336 x 025	4.5	1.8	25.3	10.5
425 x 091	10.0	2.0	32.3	19.3
544 x 216	4.0	0.8	18.5	8.5
336 x 029	5.5	1.3	12.3	3.5
155 x 526	9.3	4.8	27.8	26.3
UH 138	7.8	3.8	24.5	4.8
UH 108	1.3	11.5	20.5	15.3
SX 63	13.3	6.5	35.0	10.0
SX 9	4.5	6.5	7.5	4.5
SX 29	0.0	2.5	17.3	10.3
PX610	8.8	6.5	17.0	16.5
Mean	7.6	4.4	24.8	12.5

[a]Population in plants per acre.

[b]LSR = 11.1%.

decreased their kernel weight with the T cytoplasm (Table 9). No consistent cytoplasmic effect on kernel size was noted in this experiment.

The date at which 50% of the plants within a plot were silking varied significantly with the hybrid, population level, and cytoplasm treatments. Mid-silking date for the 15 hybrids as a mean of the 2 population levels ranged from July 25 to August 15 for fertile genotypes and July 25 to August 7 for the sterile genotypes. Tcms hybrids reached 50% silking an average 1.5 days faster than their fertile counterparts with 5 Tcms hybrids silking significantly faster. The rate of silking, days between 50 and 80%

Table 9. Kernel weight for 15 hybrids as affected by male-sterility and as a mean of 2 population levels in 1967

Hybrid	Weight per 100 kernels, grams		
	Fertile	Sterile	Mean
071 x 705	22.7[a]	24.5[a]	23.6
P3510	22.5	21.8	22.1
B14 x 577	24.2	25.2	24.7
M2036	22.4	24.1	23.2
336 x 025	23.6	21.6	22.6
425 x 091	24.0	22.7	23.4
544 x 216	24.8	23.8	24.2
336 x 029	23.4	23.6	23.5
155 x 526	23.9	26.4	25.1
UH 138	21.4	22.5	22.0
UH 108	22.2	20.6	21.4
SX 63	22.0	21.3	21.7
SX 9	26.3	24.7	25.5
SX 29	23.5	23.7	23.6
PX610	24.4	25.2	24.8
Mean	23.4	23.4	23.4

[a]LSR = 1.4 grams.

silking, varied significantly with the hybrid and population level. Only 2 hybrids (071 x 705 and P3510) silked significantly faster with the remaining 13 hybrids varying from small increases to small decreases in the silking rate as shown in Table 10.

Mid-silking date was delayed a mean 2.2 and 0.7 days by increasing the plant population from the low to high stand density for the N and T cytoplasms respectively. The mean-sterile genotype is also silked 0.5 days earlier at 18,000 plants per acre than the mean-fertile genotype whereas at 36,000 plants per acre the mean sterile silked 2.0 days earlier than the mean fertile as illustrated in Table 11. Therefore, the analysis showed a

Table 10. Mid-silking date and silking rate for 15 hybrids as affected by male-sterility and as a mean of 2 population levels in 1967

Hybrid	Mid-silking date		Days from 50-80% silked	
	Fertile	Sterile	Fertile	Sterile
071 x 705	8-14.8[a]	8-6.9[a]	7.0[b]	3.9[b]
P3510	8-10.6	8-4.4	8.0	4.1
B14 x 577	8-5.4	8-3.3	4.1	2.9
M2036	8-8.9	8-4.6	4.4	2.9
336 x 025	8-0.3	8-0.6	1.6	3.1
425 x 091	8-2.3	8-0.5	3.3	2.1
544 x 216	8-5.6	8-5.4	3.6	4.4
336 x 029	7-30.1	7-29.1	1.8	2.0
155 x 526	8-5.6	8-3.9	2.6	3.1
UH 138	8-0.6	7-30.9	2.6	2.5
UH 108	7-25.5	7-25.7	0.4	0.6
SX 63	8-6.9	8-4.9	3.8	3.4
SX 9	7-30.1	8-1.1	2.3	2.9
SX 29	8-5.4	8-4.6	3.3	2.6
PX610	8-2.9	8-3.9	2.9	4.5
Mean	8-4.1	8-2.4	3.4	3.0

[a]LSR = 1.95 days.

[b]LSR = 2.22 days.

Table 11. Mid-silking date and rate of silking for 2 population levels as affected by male-sterility and as a mean of 15 hybrids in 1967

Population (plants/a)	Mid-silking date		Days from 50 to 80% silking	
	Fertile	Sterile	Fertile	Sterile
18,000	7-30.3[a]	7-29.8[a]	2.67[b]	2.62[b]
36,000	8-1.5	7-30.5	3.87	3.13

[a]LSR = 0.7 days.

[b]LSR = 0.8 days.

significant cytoplasm by population interaction for the date of silking. Likewise, a significant interaction was observed for the cytoplasm by population interaction for the silking rate. No difference in the silking rate was observed at normal populations between the N and T cytoplasms, but a nonsignificant 0.7 days faster silking rate was observed at the high plant density. Increasing the population from 18 to 36,000 plants per acre delayed the 80% silking date a mean 1.1 and 0.5 days for the N and T cytoplasms respectively. Combining the 2.0 days earlier silking date and the 0.7 days faster silking rate, the mean-sterile genotype reached 80% silking 2.7 days earlier.

Plant height differed at greater than the 1% level of probability for hybrids and cytoplasms and at the 5% level for the hybrid by cytoplasm interaction. Fourteen of the 15 hybrids used were significantly shorter (mean 9.2 inches) with T cytoplasm than compared to their fertile counterparts as illustrated in Table 12.

Madrid 1968 (Experiment 2)

Ten single-cross hybrids with the fertile and sterile versions of each hybrid were planted at 18, 36, 54, and 72,000 plants per acre at Madrid, Iowa, in 1968. It was desired to test the effect sterile cytoplasm had on plant barrenness and yield at extremely high plant densities. Grain yield, ears per 100 plants, 75% silking date, silking rate, kernel weight, ear weight, plant lodging, and leaf area were the plant characteristics measured. Mean plant response and analysis of variance for each of these variables are presented in Appendix Tables 59 and 60 respectively.

Table 12. Plant height for 15 hybrids as affected by male-sterility and as a mean of 2 population levels in 1967

Hybrid	Plant height in inches		
	Fertile	Sterile	Mean
071 x 705	107.6[a]	100.3[a]	103.9
P3510	111.0	95.0	103.0
B14 x 577	107.0	99.6	103.3
M2036	107.6	96.8	102.2
336 x 025	101.8	91.8	96.8
425 x 091	105.5	97.1	101.3
544 x 216	108.1	98.3	103.2
336 x 029	109.5	101.5	105.5
155 x 526	100.9	89.0	94.9
UH 138	92.4	84.0	88.2
UH 108	83.9	73.0	78.4
SX 63	115.5	106.9	111.2
SX 9	99.8	88.0	93.9
SX 29	111.6	105.8	108.7
PX610	107.0	104.9	105.9
Mean	104.6	95.4	100.0

[a]LSR = 4.3 inches.

Grain yield differed at the 1% level of probability for all main effects and for the second order effects, hybrid by population and hybrid by cytoplasm interactions. Similar significance was obtained from combine grain yield as that obtained from hand yield (Appendix Table 60). Combine grain yield and grain yield on an individual plot basis and as a mean of 4 replications produced fair correlation coefficients (r = 0.83 and 0.92 respectively), however, only hand yield will be reported hereafter.

Grain yield as a mean of the 4 populations and 10 hybrids was 114.6 and 130.4 bushels per acre for the N and T cytoplasms respectively. This represents an average 13.8% higher grain yield by Tcms hybrids. Seven of the 10 hybrids yielded significantly more grain with T as compared to N cytoplasm as Figure 2 illustrates. Male-sterility's advantage for the various hybrids ranged from a -0.30 to 48.8% for B14 x 577 and P3510 respectively. B14 x 577, 336 x 025, and 336 x 029, the 3 nonsignificant hybrids for grain yield, would be considered high population tolerant genotypes with the latter 2 single-crosses being short season hybrids.

Grain yield was markedly affected by the extremely high plant densities utilized. Linear reductions in yield were noted for both the N and T cytoplasmic hybrids for the population levels used; however, sterile genotypes with 18,000 more plants per acre yielded equivalent to the fertile versions as shown in Figure 3. Interestingly enough, grain yield was 12.4% higher with T than with N cytoplasm at 18,000 plants per acre. Sterility maintained its advantage at all population levels used.

Variation for the ears per 100 plants was highly significant for the type of cytoplasm, hybrid, and population level. Seven Tcms hybrids had significantly more ear-bearing plants than their fertile counterparts as shown in Table 13; however, these hybrids were not necessarily the same 7 hybrids which yielded significantly higher with T cytoplasm. Mean barrenness was 27.0 and 18.5% for the N and T cytoplasms respectively. Table 14 presents the effect male-sterility and population level had on the ears per 100 stalks. Second ears accounted for the yield advantage of some Tcms hybrids at 18,000 plants per acre (Appendix Table 59). Fertile cytoplasm appeared to reduce the number of harvestable ears by approximately 8% at all population levels tested with a somewhat surprising 61.1% of the sterile plants at 72,000 plants per acre bearing enough grain to be considered an ear. As mentioned earlier, there was considerable stand loss at

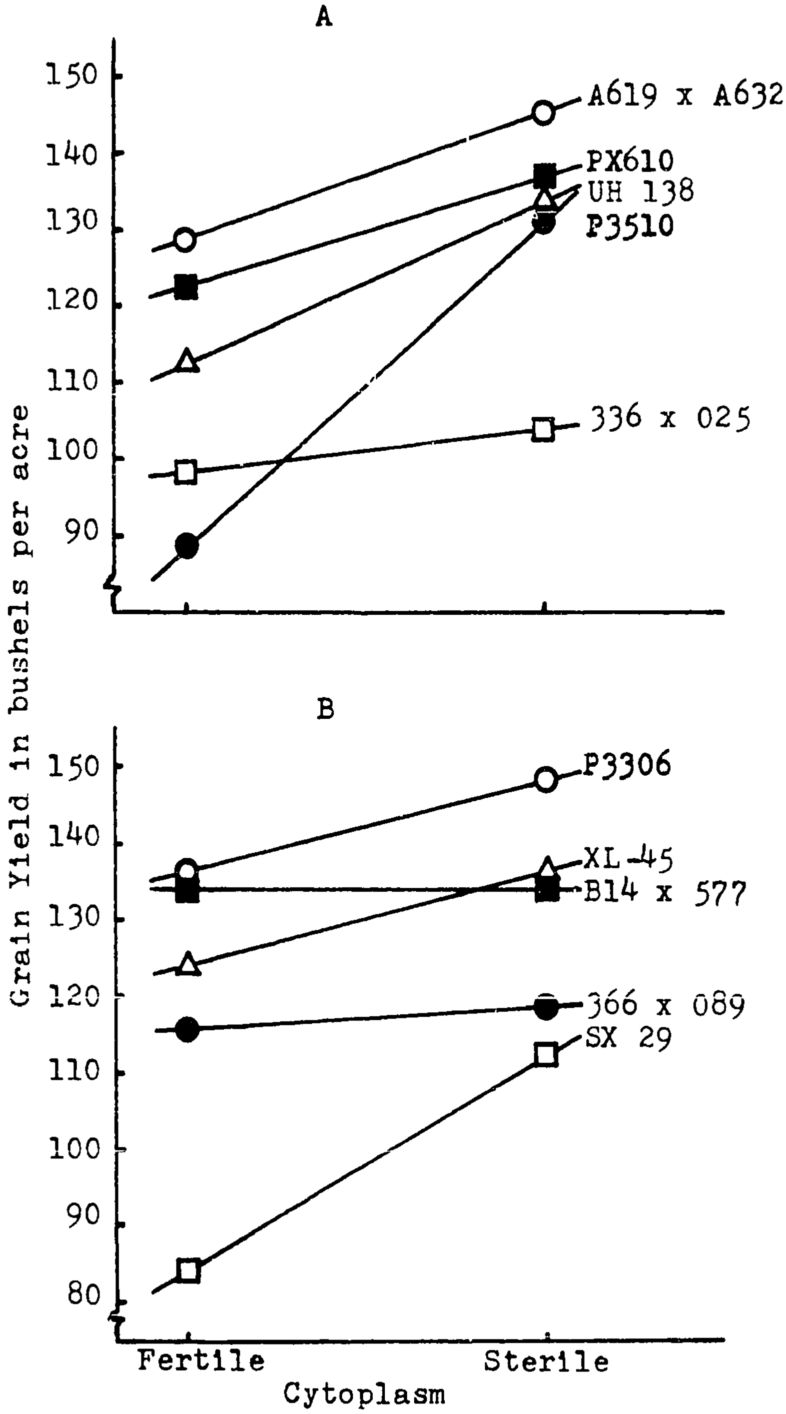

Figure 2. Grain yield for 10 hybrids (A and B) as affected by male-sterility (mean of 4 populations in 1968)

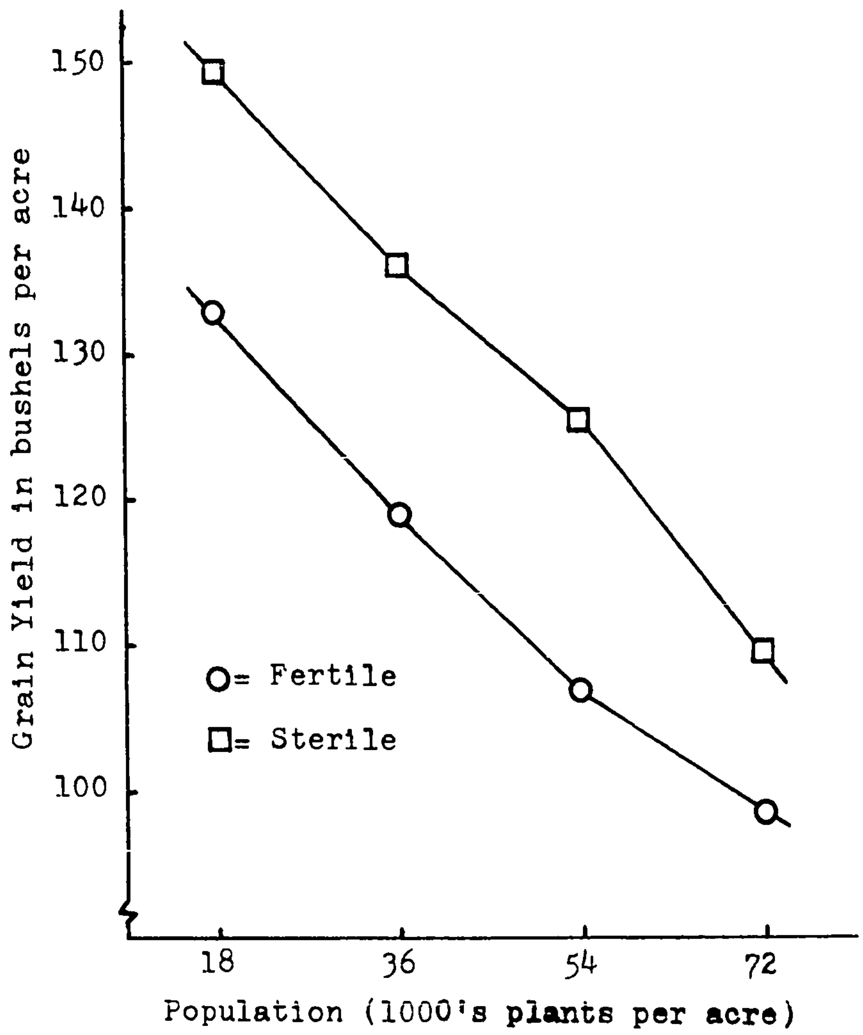

Figure 3. Grain yield for 4 population levels as affected by male-sterility (mean of 10 hybrids in 1968)

Table 13. Ears per 100 stalks for 10 hybrids as affected by male-sterility and as a mean of 4 population levels in 1968

Hybrid	Ears per 100 stalks		
	Fertile	Sterile	Mean
A619 x A632	77.0[a]	85.4[a]	81.2
UH 138	68.3	81.1	74.7
P3510	51.6	72.3	61.9
336 x 025	74.9	83.2	79.0
P3306	75.3	79.3	77.3
B14 x 577	79.4	84.1	81.8
336 x 029	80.6	86.8	83.7
SX 29	67.8	76.9	72.3
PX610	77.6	80.1	78.8
XL-45	77.6	86.0	81.8
Mean	73.0	81.5	77.3

[a]LSR = 5.9 ears/100 stalks.

Table 14. Ears per 100 stalks for 4 population levels as affected by male-sterility and as a mean of 10 hybrids in 1968

Population (plants/a)	Ears per 100 stalks		
	Fertile	Sterile	Mean
18,000	96.8[a]	103.8[a]	100.3
36,000	77.1	87.6	82.4
54,000	64.2	73.5	68.8
72,000	53.9	61.1	57.5
Mean	73.0	81.5	77.3

[a]LSR = 3.7 ears/100 stalks.

these extremely high plant densities. Since the plant characteristic, the ears per 100 stalks, was calculated on the harvest population, percent barrenness was a conservative estimate.

The remaining 2 yield components, ear weight and kernel weight, are presented in Table 15. Ear and kernel weights differed significantly for

Table 15. Ear and kernel weight for 10 hybrids as affected by male-sterility and as a mean of 4 population levels in 1968

Hybrid	Ear weight in grams			Weight/100 seeds in grams		
	Fertile	Sterile	Mean	Fertile	Sterile	Mean
A619 x A632	137[a]	136[a]	136	28.3[b]	27.8[b]	28.1
UH 138	132	138	135	24.0	23.9	23.9
P3510	141	147	144	27.5	27.3	27.4
336 x 025	103	100	101	21.2	20.2	20.7
P3306	150	155	152	31.2	31.6	31.4
B14 x 577	135	129	131	27.7	27.0	27.4
336 x 029	114	110	112	21.2	20.2	20.7
SX 29	109	117	113	25.4	25.4	25.4
PX610	132	139	135	27.4	28.0	27.7
XL-45	126	126	126	26.1	24.3	25.2
Mean	128	130	129	26.0	25.6	25.8

[a]LSR = 9.7 grams.

[b]LSR = 0.7 grams.

the hybrid, population level, and population by hybrid interaction mainly due to the diversity of the hybrids and extreme population levels used. The kernel weight was reduced significantly by the T cytoplasm (mean 0.4 grams per 100 seed). Seven Tcms hybrids, B14 x 577, 336 x 029, 336 x 025, and XL-45 significantly, exhibited reduced kernel weights. It is interesting to note that the first 3 of these hybrids are the varieties which did not respond to male-sterility in terms of grain yield. Ear weight, on the other hand, was increased by the T cytoplasm by only 2 grams per ear. None of the hybrids as a mean of the 4 populations differ significantly in ear weight due to the type of cytoplasm. Ear weight was significantly higher with sterile cytoplasm at 18,000 plants per acre, but the remaining populations were unaffected by male-sterility (Table 16). Both ear and kernel

Table 16. Ear and kernel weight for 10 hybrids as affected by male-sterility and population level and as a mean of 10 hybrids in 1968

Population (plants/a)	Ear weight in grams		Weight/100 seeds in grams	
	Fertile	Sterile	Fertile	Sterile
18,000	190[a]	199[a]	27.8[b]	27.0[b]
36,000	122	124	25.5	25.1
54,000	103	102	25.4	25.3
72,000	95	93	25.2	24.9
Mean	128	130	26.0	25.6

[a]LSR = 6.1 grams.

[b]LSR = 0.5 grams.

weights drop substantially by increasing the population from 18 to 36,000 plants per acre; further increases in plant density had only slight effects on the kernel weight and modest effects on the ear weight.

Mean plant lodging (root lodging and stalk breakage) was 13.4, 23.7, 30.6, and 33.8% for 18, 36, 54, and 72,000 plants per acre. Male-sterility had little influence on the number of plants lodged; however, at 36 and

54,000 plants per acre, the sterile versions lodged approximately 5% more than fertile versions. The hybrid influenced the amount of lodging that occurred. UH 138, B14 x 577, and XL-45 exhibited little lodging while 336 x 025, 336 x 029, and PX610 exhibited severe lodging as shown in Appendix Table 59.

Leaf area index (LAI) differed at greater than the 1% level of probability for the treatments, hybrids, populations, and cytoplasms. Mean LAI's were 3.3, 6.1, 8.5, and 10.6 for 18, 36, 54, and 72,000 plants per acre respectively. The hybrid B14 x 577 had the highest mean LAI (8.1) and the 2 early varieties, 336 x 029 and 336 x 025, had the lowest mean LAI (5.8 and 6.1 respectively). Male-sterility decreased mean LAI's by 0.26 with lesser reductions at 18,000 plants per acre than 72,000 plants per acre (Table 17); however, the interaction of population by cytoplasm was nonsignificant.

Table 17. LAI for the 4 population levels as affected by male-sterility and as a mean of 10 hybrids in 1968

Population (plants/a)	Leaf area index		
	Fertile	Sterile	Mean
18,000	3.32[a]	3.24[a]	3.28
36,000	6.22	6.02	6.12
54,000	8.61	8.42	8.51
72,000	10.91	10.37	10.64
Mean	7.27	7.01	7.14

[a]LSR = 0.32.

The 75% silking date was significantly earlier (mean 3.7 days with the T than N cytoplasm as can be seen in Table 18 for the 10 hybrids). All

Table 18. 75% silking date for 10 hybrids as affected by male-sterility and as a mean of 4 population levels in 1968

Hybrid	75% silking date		
	Fertile	Sterile	Mean
A619 x A632	7-26.3[a]	7-21.4[a]	7-25.1
UH 138	7-28.4	7-23.3	7-25.9
P3510	8-6.1	8-1.6	8-3.9
336 x 025	7-22.1	7-21.0	7-21.5
P3306	8-0.7	7-29.0	7-30.3
B14 x 577	7-30.0	7-26.5	7-28.3
336 x 029	7-22.5	7-20.8	7-21.7
SX 29	8-0.7	7-27.6	7-29.6
PX610	7-28.0	7-23.3	7-25.6
XL-45	7-25.2	7-21.5	7-23.3
Mean	7-28.3	7-24.7	7-26.5

[a]LSR = 2.6 days.

hybrids silked earlier (mean 1.0 days) and faster (mean 2.6 days) in the presence of the sterile cytoplasm. Eight hybrids differed significantly for the date at which 75% of the plants were silking including all hybrids which differed significantly for grain yield.

Stand density interacted with the cytoplasm in regard to the silking date and rate. Mean days between the N and T cytoplasms' 75% silking dates were 0.4, 3.4, 5.3, and 5.3 days for 18, 36, 54, and 72,000 plants per acre respectively. Increasing the population from 18 to 36,000 plants per acre delayed the mean silking date 5.7 days for the N cytoplasmic hybrids whereas only 2.7 days delay was noted for the T cytoplasmic hybrids. Both the rate and date of silking contributed to the earlier 75% silking date. Male-sterility increased the mean silking rate by 2.8 days. At 18,000 plants per acre, there was only 0.2 days difference in the silking rate between the N and T cytoplasms (Table 19), but at 36,000 plants per acre, there was 2.6 days difference in the silking rate in favor of the Tcms

Table 19. 75% silking date and silking rate for 4 population levels as affected by male-sterility and as a mean of 10 hybrids in 1968

Population (plants/a)	75% silking date		Days between 25 & 75% silking	
	Fertile	Sterile	Fertile	Sterile
18,000	7-20.9[a]	7-20.5[a]	2.2[b]	2.0[b]
36,000	7-26.6	7-23.2	6.3	3.7
54,000	8-0.8	7-26.5	10.3	6.2
72,000	8-2.8	7-28.5	12.2	7.7
Mean	7-28.3	7-24.7	7.7	4.9

[a] LSR = 1.7 days.

[b] LSR = 1.6 days.

hybrids. Thus, a mean-sterile genotype silked 0.6 days earlier and 2.4 days faster when the population was increased from 18 to 36,000 plants per acre as compared to the mean-fertile genotype. This earliness could give Tcms hybrids a definite advantage at the higher plant densities.

Madrid 1969 (Experiment 3)

Ten single-cross corn hybrids with both the N and T cytoplasms were planted at 18 and 36,000 plants per acre at Madrid, Iowa, in 1969. The following plant characteristics were measured: grain yield, barrenness, ear weight, kernel weight, 75% silking date, silking rate, leaf area, grain per unit leaf area, shelling percentage, harvest moisture, and plant lodging. Mean plant response for each plant characteristic measured is presented in Appendix Tables 61 and 63 with each analysis of variance presented in Appendix Table 62.

Grain yield and combine grain yield gave poor correlations in 1969 (r = 0.57 and 0.78 on an individual plot basis and as a mean of the 4 replications respectively) primarily due to the severe damaging wind on September 6; therefore, all subsequent yields will be reported on hand harvest estimates.

Grain yield was similar to the previous 2 years in that hybrids, cytoplasms, and the hybrid by population interaction differed significantly; however, 2 marked exceptions occurred. Grain yield response to the type of cytoplasm was 9.8 bushels per acre (6.7%) in favor of the Tcms hybrids. One hybrid (155 x 526) gave a slight yield reduction of 3.5 bushels per acre (2.5%) while the hybrids (XL-45, A619 x A632, P3510, and 071 x 705) yielded significantly higher with sterile cytoplasm, as illustrated in Figure 4; hence, there was a nonsignificant hybrid by cytoplasm interaction. Secondly, the population level as a mean of the cytoplasm types did not differ significantly; however, as Figure 5 illustrates, an interaction between the cytoplasm type and population level occurred. Tcms hybrids as a mean yielded 2.3 and 17.3 bushels per acre (1.5 and 12.3%) higher than their fertile counterparts at 18 and 36,000 plants per acre respectively. Sterile genotypes at the high stand level yielded a significant 5.9 bushels per acre more shelled corn than fertile genotypes at the normal population,

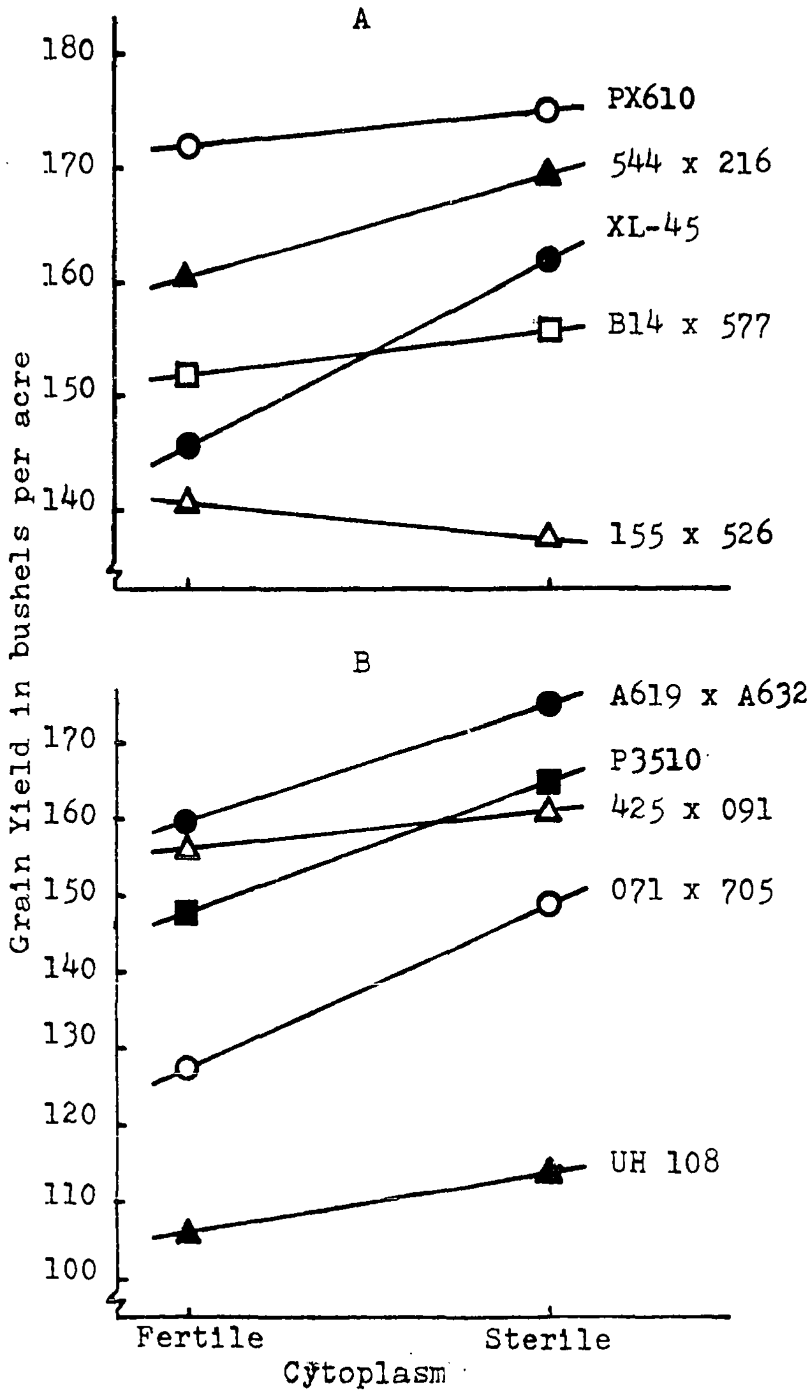

Figure 4. Grain yield for 10 hybrids (A and B) as affected by male-sterility (mean of 2 populations in 1969)

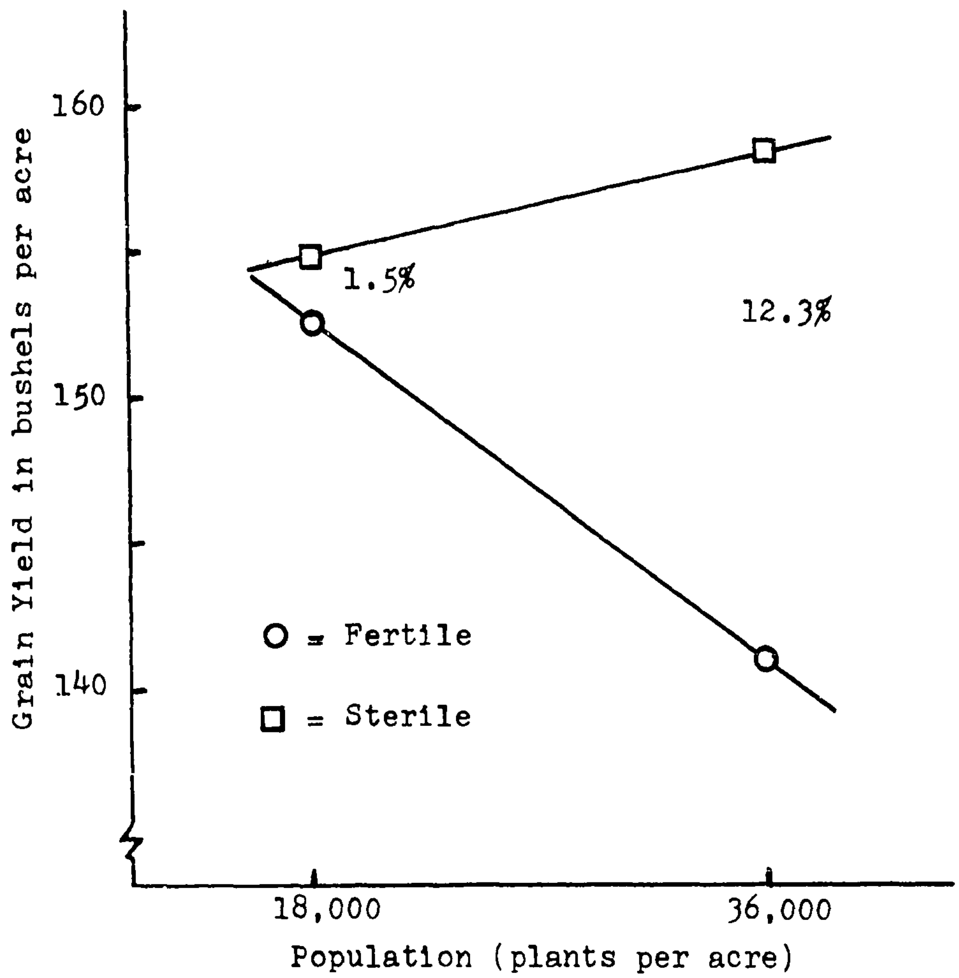

Figure 5. Grain yield for 2 populations as affected by male-sterility (mean of 10 hybrids in 1969)

but fertile genotypes yielded 11.4 bushels per acre less at the high stand level as compared to their yield at the low stand level. In other words, male-sterility increased (doubled in this case) the tolerance of the hybrids studied for population stresses.

The yield components, barrenness, ear weight, and kernel weight, differed at the 1% level of probability for hybrids, populations, cytoplasms, and the hybrid by population interaction. Percent barrenness (including both nubbin producing and physiological barren plants), ear weight, and kernel weight for the N and T versions of each hybrid are presented in Tables 20 and 21. Plant barrenness was the component of yield which

Table 20. Percent barrenness and number of ears per plot for 10 hybrids as affected by male-sterility and as a mean of 2 population levels in 1969

	Percent barrenness			Ears per plot		
Hybrid	Fertile	Sterile	Mean	Fertile	Sterile	Mean
PX610	8.7[a]	6.9[a]	7.8	28.8[b]	28.0[b]	28.4
XL-45	14.7	10.7	12.7	26.9	29.1	28.0
B14 x 577	14.2	11.8	13.0	27.6	27.9	27.8
A619 x A632	10.2	4.3	7.3	26.8	31.4	29.1
P3510	18.5	4.6	11.6	25.8	28.5	27.1
UH 108	13.1	8.1	10.6	25.8	27.3	26.5
155 x 526	14.1	11.5	12.8	23.9	26.4	25.1
425 x 091	16.2	7.6	11.9	25.8	29.4	27.6
544 x 216	10.4	5.9	8.1	25.8	27.8	26.8
071 x 705	34.6	11.2	22.9	18.4	26.3	22.3
Mean	15.5	8.3	11.9	25.5	28.2	26.9

[a]LSR = 5.6%.

[b]LSR = 2.3 ears.

Table 21. Ear weight and kernel weight for 10 hybrids as affected by male-sterility and as a mean for 2 population levels in 1969

Hybrid	Ear weight grams/ear			Kernel weight grams/100 seed		
	Fertile	Sterile	Mean	Fertile	Sterile	Mean
PX610	182[a]	185[a]	183	28.6[b]	28.0[b]	28.3
XL-45	183	181	182	28.1	26.5	27.3
B14 x 577	182	178	180	28.4	28.0	28.2
A619 x A632	184	179	182	29.8	30.5	30.2
P3510	198	173	185	25.7	23.8	24.7
UH 108	113	115	114	24.5	24.1	24.3
155 x 526	168	164	166	29.0	28.0	28.5
425 x 091	186	175	180	27.1	24.9	26.0
544 x 216	186	185	186	30.1	29.2	29.6
071 x 705	166	143	154	22.7	24.5	23.6
Mean	175	168	171	27.4	26.8	27.1

[a]LSR = 13.8 grams.

[b]LSR = 1.1 grams.

explained the majority of the decreased grain yield of normal hybrids relative to the Tcms hybrids. At the high stand density, 3 of the 4 hybrids that differed significantly for grain yield were also significantly different in the number of barren plants. Mean barrenness was 15.5 and 8.3% for the N and T cytoplasmic versions respectively. All Tcms hybrids had a lower percentage barren plants than fertile hybrids. The population intolerant Tcms hybrid, 071 x 705, decreased its barrenness 23.4% relative to the fertile version. Male-sterility influenced population tolerant Tcms hybrids' (B14 x 577 and PX610) barrenness to a lesser degree. Barrenness for these 2 hybrids was reduced 2.4 and 1.8% respectively relative to the fertile versions.

Male-sterility reduced kernel weight 0.6 grams per 100 seed while it reduced ear weight 7 grams per ear. Kernel weight was reduced significantly for 3 Tcms hybrids but increased significantly for 1 Tcms hybrid; this gave a significant interaction for the hybrid by cytoplasm. Ear weight was significantly decreased in only 2 Tcms genotypes (071 x 705 and P3510).

Stand density had a marked effect on the yield components as illustrated in Table 22. Cytoplasmic influence on the number of barren plants

Table 22. Components of yield for 2 population levels as affected by male-sterility and as a mean of 10 hybrids in 1969

Population (plants/a)	Cytoplasm	% barrens	Ear wt. grams	Grams/ 100 seed
18,000	F	7.4[a]	221.0[b]	28.7[c]
	S	3.3[a]	214.9[b]	28.0[c]
36,000	F	23.6[a]	128.4[b]	26.1[c]
	S	13.2[a]	120.5[b]	25.5[c]
Mean	F	15.5	174.7	27.4
	S	8.3	167.7	26.8

[a]LSR = 2.5%.

[b]LSR = 6.2 grams.

[c]LSR = 0.5 grams.

at the 2 population levels was of major interest. Sterile cytoplasm decreased plant barrenness 4.1% for the normal plant density and 10.4% for the high plant density causing a significant cytoplasm by population interaction. This plant characteristic accounted for the yield differences that were observed between population levels. In fact, decreased barrenness had to compensate for the reduced ear and kernel weights associated with the T cytoplasm in order to exhibit the noted yield advantage. Mean response to the type of cytoplasm for ear and kernel weights was not influenced by the stand level.

One factor which could explain the reduced number of barren plants by Tcms hybrids was the date at which 75% of the plants were silking. Table 23 shows the effect the N and T cytoplasms had on the silking date for 10

Table 23. 75% silking date for 10 hybrids as affected by male-sterility and as a mean of 2 population levels in 1969

	Date of 75% silking			
	18,000		36,000	
Hybrids	Fertile	Sterile	Fertile	Sterile
PX610	7-17.4[a]	7-16.8[a]	7-19.3[a]	7-19.2[a]
XL-45	7-15.4	7-15.2	7-17.8	7-15.6
B14 x 577	7-21.5	7-20.6	7-25.5	7-21.6
A619 x A632	7-14.7	7-14.8	7-18.4	7-15.1
P3510	7-20.7	7-18.9	7-23.5	7-20.9
UH 108	7-10.8	7-9.2	7-13.4	7-10.8
155 x 526	7-23.7	7-19.8	7-25.7	7-21.9
425 x 091	7-18.1	7-17.4	7-23.8	7-18.8
544 x 216	7-19.5	7-19.4	7-23.4	7-22.9
071 x 705	7-25.6	7-23.6	8-9.0	7-29.5
Mean	7-18.7	7-17.6	7-23.0	7-19.6

[a]LSR = 2.1 days.

single-cross hybrids at 2 stand levels. The silking date was significantly affected by all first order and second order effects. The 75% silking date was reduced by a mean 2.3 days with T as compared to N cytoplasm. Male-sterility significantly reduced the 75% silking date for 1 hybrid at 18,000 plants per acre whereas at 36,000 plants per acre 8 hybrids were significantly reduced. The high population delayed the silking date a mean 3.1 days when compared to the normal population. Tcms hybrids were delayed 2.0 days while normal hybrids were delayed 4.3 days by increasing the stand level from 18 to 36,000 plants per acre.

The silking rate, a relative measure of the pollen-silking interval, is shown in Table 24 for the 10 hybrids. The silking rate differed significantly for the hybrid, population level, type of cytoplasm, and the interactions, hybrid by population and population by cytoplasm. Male-sterility decreased the days between 25 and 75% silking by 0.3 and 1.6 days at the normal and high stand densities respectively. Hybrids had a marked effect on this silking rate response. The variety 071 x 705 had the slowest silk-

Table 24. Rate of silking for 10 hybrids as affected by male-sterility and population level in 1969

	Days between 25 and 75% silking			
	18,000		36,000	
Hybrid	Fertile	Sterile	Fertile	Sterile
PX610	2.2[a]	1.5[a]	2.6[a]	2.5[a]
XL-45	1.3	1.2	1.9	1.4
B14 x 577	1.8	2.1	4.6	3.0
A619 x A632	0.9	1.3	4.1	1.2
P3510	2.1	1.5	2.9	2.4
UH 108	2.2	1.0	3.5	2.0
155 x 526	2.7	1.9	3.4	2.2
425 x 091	1.5	1.4	5.4	2.2
544 x 216	2.0	1.8	2.8	3.0
071 x 705	2.8	2.0	12.8	6.0
Mean	1.9	1.6	4.2	2.6

[a]LSR = 1.9 days.

ing rate at both populations and had the largest silking rate decrease due to male-sterility. Population tolerant varieties, such as PX610, XL-45, and B14 x 577, were less influenced by male-sterility in regard to the silking rate (Table 24).

Leaf area index (LAI) and grain yield per unit leaf area are presented in Table 25. LAI and grain yield per unit leaf area differed at the 1%

Table 25. LAI and yield per unit leaf area for 10 hybrids as affected by male-sterility and as a mean of 2 population levels in 1969

Hybrid	LAI			Grain per unit leaf area grams/dm^2		
	Fertile	Sterile	Mean	Fertile	Sterile	Mean
PX610	4.09[a]	4.26[a]	4.18	2.66[b]	2.61[b]	2.63
XL-45	3.46	3.62	3.54	3.06	2.99	3.03
B14 x 577	4.79	4.51	4.65	2.15	2.32	2.24
A619 x A632	3.70	3.40	3.55	3.02	3.37	3.19
P3510	4.31	4.11	4.21	2.46	2.65	2.55
UH 108	2.72	2.67	2.70	2.39	2.64	2.51
155 x 526	4.50	4.17	4.34	2.15	2.26	2.21
425 x 091	4.05	3.55	3.80	2.51	2.92	2.71
544 x 216	4.83	4.66	4.74	2.28	2.45	2.37
071 x 705	5.16	4.86	5.01	1.42	1.68	1.55
Mean	4.16	3.98	4.07	2.41	2.59	2.50

[a]LSR = 0.26.

[b]LSR = 0.23 gm/dm^2.

level of probability for all main effects and the hybrid by population interaction. The LAI as a mean of the 10 hybrids was 4.16 and 3.98 for the N and T cytoplasmic hybrids respectively. A significant hybrid by cytoplasm interaction was caused by 4 hybrids (A619 x A632, 155 x 526, 425 x 091, and 071 x 705) which significantly decreased their LAI's in T as compared to N cytoplasm while PX610 approached significance for having a larger LAI with the T cytoplasm. Grain per unit leaf area was significantly greater for 4 male-sterile hybrids (A619 x A632, UH 108, 425 x 091, and 071 x 705) with a mean response to cytoplasm type at 2.41 and 2.59 grams/dm^2 for the N and T cytoplasms respectively. Increasing the population level from 18 to 36,000 plants per acre decreased the grain per unit leaf area from 3.23 to 1.76 grams/dm^2 with the advantage in grain per unit leaf area for Tcms hybrids at 0.18 grams/dm^2 for both plant densities. A significant population by cytoplasm interaction was not found for either leaf area or grain per unit leaf area.

The shelling percentage differed significantly for hybrids only. B14 x 577 and 544 x 216 were significantly lower while 425 x 091 was significantly higher in their shelling percentage than the other hybrids as can be seen in Appendix Tables 61 and 63. Cytoplasm type had no consistent effect on the shelling percentage.

The harvest moisture was cytoplasmically influenced. Percent moisture differed at the 1% level of probability for the hybrid, cytoplasm, and the interactions, cytoplasm by hybrid and population by hybrid. Male-sterility reduced the percent moisture by 0.9% as illustrated in Table 26. This difference is highly significant but would be considered of little practical importance.

The percent lodging (root lodging and stalk breakage) was extremely high in this experiment as seen in Table 26 for the fertile and sterile versions of the various hybrids. Lodging was rated as 24.3 and 36.4% of the harvest plants for the N and T cytoplasms respectively. The lodging rate was considered unbiased; therefore, sterility significantly increased

Table 26. Harvest moisture and percent lodging for 10 hybrids as affected by male-sterility and as a mean for 2 population levels in 1969

Hybrid	Percent moisture			Percent lodging		
	Fertile	Sterile	Mean	Fertile	Sterile	Mean
PX610	19.1[a]	18.4[a]	18.7	38.1[b]	47.5[b]	42.8
XL-45	20.2	18.3	19.2	11.9	30.6	21.3
B14 x 577	16.9	14.9	15.9	21.9	34.4	28.1
A619 x A632	17.0	16.5	16.7	46.3	55.6	50.9
P3510	20.4	19.4	19.9	35.0	66.3	50.6
UH 108	20.0	20.0	20.0	18.1	20.0	19.1
155 x 526	24.3	22.8	23.5	33.1	51.3	42.2
425 x 091	19.4	18.6	19.0	30.0	44.4	37.2
544 x 216	19.6	18.8	19.2	8.8	14.4	11.6
071 x 705	32.5	32.5	32.5	0.0	0.0	0.0
Mean	20.9	20.0	20.4	24.3	36.4	30.4

[a]LSR = 0.7%.

[b]LSR = 12.2%.

lodging. Population level gave much the same lodging rating as did the type of cytoplasm (22.2 and 38.6% lodged plants for the normal and high stand densities respectively).

Madrid 1969 (Experiment 4)

Five single-cross corn hybrids, chosen for their tolerance to population stresses with the fertile and sterile counterparts of each, were planted at 18, 24, 30, 36, and 54,000 plants per acre at Madrid, Iowa, in 1969. It seemed desirable to investigate the effect cytoplasmic male-sterility had on a range of normal to high stand levels. The following eleven plant characteristics were measured: grain yield, barrenness, ear weight, kernel weight, 75% silking date, silking rate, leaf area, grain per unit leaf area, lodging, harvest moisture, and shelling percentage. Mean plant response and the analysis of variance for each plant characteristic measured are presented in Appendix Tables 63 and 64 respectively.

Grain yield and combine grain yield elicited similar analyses of variance except blocks were significant for combine grain yield. However, linear comparisons of the nonsignificant population by cytoplasm and hybrid by cytoplasm interactions elicited different results. Correlation coefficients were quite poor on an individual treatment basis but somewhat better on a mean basis ($r = 0.57$ and 0.83 respectively). Due to the poor correlation caused by severe wind damage sustained on September 6, subsequent yields will be reported on hand harvest only.

Grain yield differed at the 1% level of probability for all main effects and the second order effect, hybrid by population. Figure 6 shows the effect Tcms had on grain yield for the 5 varieties utilized. Tcms hybrids yielded a mean 8.1 bushels per acre (5.2%) greater than the mean 156.5 bushels per acre produced by the normal hybrid. All hybrids, PX610 and XL-45 significantly, yielded more grain with the T than the N cytoplasm. The significant population by hybrid interaction was caused by varieties PX610 and A619 x A632 yielding similarily at 24, 30, and 36,000 plants per acre while the remaining varieties maximized their yields around 24,000 plants per acre and rapidly declined thereafter.

Stand density interacted with the type of cytoplasm to produce an interesting and highly important effect. The analysis of variance showed a significant quadratic effect within the nonsignificant population by cytoplasm interaction. This is readily evident from Figure 7. Mean grain yield was 157.3, 168.4, 161.1, 154.1, and 141.5 bushels per acre for the N

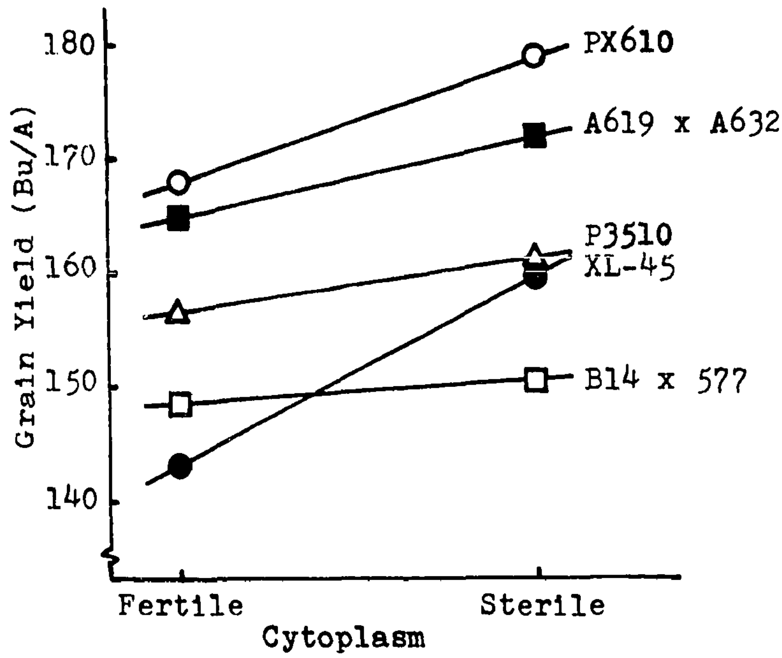

Figure 6. Grain yield of the fertile and sterile counterparts of 5 hybrids (mean of 5 populations in 1969)

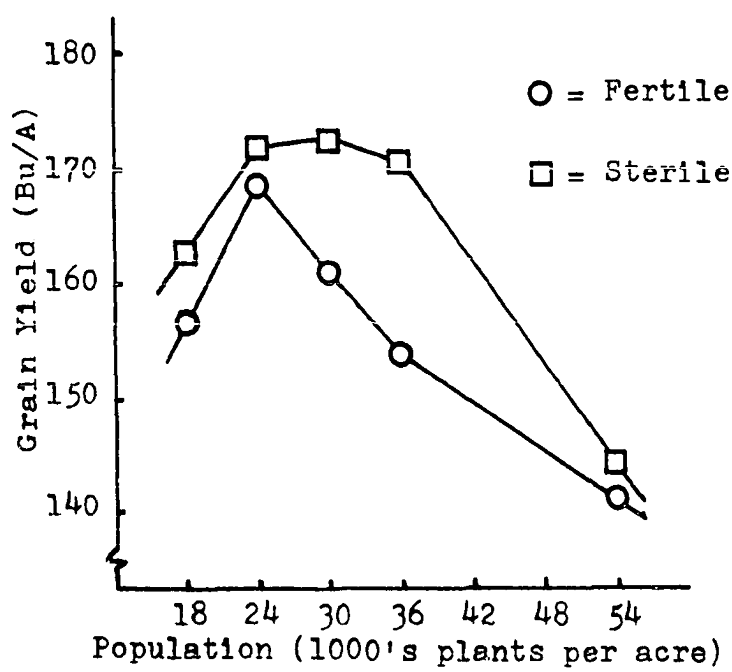

Figure 7. Grain yield as affected by male-sterility and population level (mean of 5 hybrids in 1969)

cytoplasm and 163.0, 172.1, 172.7, 170.9, and 144.4 bushels per acre for the T cytoplasm at 18, 24, 30, 36, and 54,000 plants per acre respectively. At 18, 24, and 54,000 plants per acre the T cytoplasm had little effect on mean grain yield (3.6, 2.2, and 2.0% advantage respectively); however, at 30 and especially 36,000 plants per acre grain yield was significantly increased (7.2 and 10.9% respectively) by the T cytoplasm as compared to its normal counterpart. In other words, the tolerance to population stresses with respect to grain yield of these 5 hybrids was substantially increased by cytoplasmic male-sterility. Grain yields at the optimum population for the N and T cytoplasms, however, were similar.

Barrenness differed significantly for the main effects only. Male-sterility reduced the number of barren plants (physiological barren plants and nubbin ear producers) as a mean of the 5 populations and hybrids by 5.4% (16.7% versus 11.3% for the N and T cytoplasms respectively) as shown in Table 27. Male-sterility had little effect on barrenness at 18,000

Table 27. Percent barrenness as affected by male-sterility and population level and as a mean of 5 hybrids in 1969

Population (plants/a)	Percent barrenness		
	Fertile	Sterile	Mean
18,000	7.8[a]	3.7[a]	5.8
24,000	8.9	4.5	6.7
30,000	12.0	7.3	9.6
36,000	18.8	11.6	15.2
54,000	35.8	29.1	32.5
Mean	16.7	11.3	14.0

[a]LSR = 3.9%.

plants per acre for all hybrids except P3510, but at 30 and 36,000 plants per acre, male-sterility consistently reduced the number of barren plants (Appendix Table 63). The number of ears per plot gave a significant linear effect for the population by cytoplasm interaction. The larger number of ears at higher stand levels by Tcms hybrids was the major factor which attributed to the higher grain yields by T cytoplasm at 30 and 36,000 plants per acre as previously noted. However, the linear component of the population by cytoplasm interaction for barrenness was not significant, apparently, due to the high coefficient of variation (45.1%) for this plant attribute.

Population level, hybrid, and the population by hybrid interaction, as expected, differed significantly for the plant characteristic, ear weight. Male-sterility had little effect on ear weight at 18 through 36,000 plants per acre as noted in Table 28; however, male-sterility did significantly

Table 28. Ear weight as affected by male-sterility and population level and as a mean of 5 hybrids in 1969

Population (plants/a)	Ear weight in grams per ear		
	Fertile	Sterile	Mean
18,000	203[a]	204[a]	204
24,000	186	184	185
30,000	156	156	156
36,000	138	141	139
54,000	115	108	112
Mean	160	158	159

[a]LSR = 6.1 grams.

reduce the ear weight at 54,000 plants per acre. Varieties PX610 and XL-45 had heavier ear weights while the variety A619 x A632 had a lighter ear weight with T as compared to N cytoplasm which led to a significant hybrid by cytoplasm interaction for ear weight.

The remaining yield component, kernel weight, differed at the 1% level of probability for all main effects and the second order effects, hybrid by population and hybrid by cytoplasm interactions. Weight per 100 seed was less for all 5 hybrids with sterile cytoplasm (26.8 versus 27.5 grams per 100 seed for the fertile cytoplasm) as shown in Table 29. The kernel

Table 29. Kernel weight for 5 hybrids as affected by male-sterility and as a mean of 5 population levels in 1969

Hybrid	Kernel weight in grams per 100 seed		
	Fertile	Sterile	Mean
PX610	27.5[a]	27.7[a]	27.6
XL-45	27.8	26.0	26.9
B14 x 577	27.5	27.3	27.4
A619 x A632	29.4	28.9	29.2
P3510	25.2	23.9	24.6
Mean	27.5	26.8	27.1

[a]LSR = 0.8 grams.

weight for the Tcms genotypes of XL-45 and P3510 was reduced significantly and the Tcms of PX610 was increased slightly by the T cytoplasm leading to a significant hybrid by cytoplasm interaction. Male-sterility had little effect on the kernel weight at various population levels, but the population level had an interesting effect on kernel weight. Kernel weight was 29.1, 27.8, 26.6, 26.4, and 25.8 grams per 100 seed for 18, 24, 30, 36, and 54,000 plants per acre respectively. Increasing the population from 18 to 24,000 plants per acre decreased the weight per 100 seed by 1.7 grams while increasing the stand from 18 to 36 or 54,000 plants per acre decreased the weight per 100 seed 2.6 and 3.1 grams respectively.

The silking date differed at the 1% level of probability for the hybrid, population level, and cytoplasm type and at the 5% level for the interactions, hybrid by population and hybrid by cytoplasm. Male-sterility decreased the mean number of days to obtain 75% silking by 1.2 days (Table 30). Increasing the stand density from 18 to 36,000 plants per acre

Table 30. 75% silking date and rate of silking for 5 population levels as affected by male-sterility and as a mean of 5 hybrids in 1969

Population	Mean 75% silking date			Mean days from 25 to 75% silking		
(plants/a)	Fertile	Sterile	Mean	Fertile	Sterile	Mean
18,000	7-18.0[a]	7-17.2[a]	7-17.6	1.8[b]	1.5[b]	1.6
24,000	7-18.5	7-17.5	7-18.0	2.0	1.5	1.8
30,000	7-19.2	7-18.1	7-18.6	2.5	1.8	2.1
36,000	7-20.7	7-18.5	7-19.6	3.2	2.1	2.7
54,000	7-22.6	7-21.5	7-22.0	4.0	3.6	3.8
Mean	7-19.8	7-18.6	7-19.1	2.7	2.1	2.4

[a]LSR = 0.9 days.

[b]LSR = 0.7 days.

delayed the 75% silking date by 2.7 and 1.3 days for the N and T cytoplasms respectively. Tcms hybrids reached the 75% silking date 0.8 days earlier than the normal hybrids at 18,000 plants per acre whereas at 36,000 plants per acre Tcms hybrids reached the 75% silking date 2.2 days earlier. This produced a significant quadratic effect at the 10% level for the population by cytoplasm interaction.

Male-sterility's advantage in date of 75% silking was the result of an average 0.6 days earlier silk emergence and a 0.6 days faster rate of silking. The silking rate differed significantly for all main effects. Each increase in the stand density increased the silking rate as illustrated in Table 30. The silking rate for the T cytoplasm was 0.3 and 1.1 days faster than the N cytoplasm at 18 and 36,000 plants per acre respectively. The quadratic component of the population by cytoplasm interaction for silking rate also approached the 5% level of significance. Increasing the stand from 18 to 36,000 plants per acre increased the number of days to obtain 75% silking by 1.4 and 0.6 days for the N and T cytoplasms respectively. Therefore, the 2.2 days earlier 75% silking date noted above for the sterile genotype at 36,000 plants per acre was the result of a 1.1 days faster silking rate and 1.1 days earlier silk emergence.

Leaf area index (LAI) varied with the hybrid, population level, and cytoplasm type. Male-sterile cytoplasm reduced the LAI from an average 4.75 for normal hybrids to 4.62 for the Tcms hybrids as shown in Table 31. The LAI was generally reduced at all stand levels by male-sterility but only at 54,000 plants per acre was the LAI significantly different.

Grain per unit leaf area as affected by male-sterility and population level is presented in Table 32. Cytoplasms, hybrids, population levels,

Table 31. LAI as affected by male-sterility and population level and as a mean of 5 hybrids in 1969

Population (plants/a)	Leaf area index		
	Fertile	Sterile	Mean
18,000	2.84[a]	2.76[a]	2.80
24,000	3.79	3.69	3.74
30,000	4.70	4.54	4.62
36,000	5.29	5.20	5.24
54,000	7.14	6.91	7.03
Mean	4.75	4.62	4.68

[a]LSR - 0.23.

Table 32. Grain per unit leaf area as affected by male-sterility and population level and as a mean of 5 hybrids in 1969

Population (plants/a)	Yield in grams per decimeter squared		
	Fertile	Sterile	Mean
18,000	3.53[a]	3.76[a]	3.64
24,000	2.84	2.95	2.89
30,000	2.18	2.42	2.30
36,000	1.86	2.09	1.98
54,000	1.26	1.33	1.30
Mean	2.33	2.51	2.42

[a]LSR = 0.17 grams.

and the hybrid by population interaction differed significantly for grain yield per unit leaf area. Sterile cytoplasm increased the grain yielding efficiency by a mean 0.18 grams/dm^2. Grain per unit leaf area was 0.23 grams/dm^2 higher for the T as compared to N cytoplasm at both 18 and 36,000 plants per acre respectively. The difference in quadratic response of cytoplasm type to population level noted for grain yield was not found statistically with grain per unit leaf area. However, if one decodes the yield (removes the leaf area variation), the greater productivity of the T cytoplasm at higher stand densities can be observed in the leaf efficiency measurement also.

Lodging ratings were extremely high for this experiment due to a 90 mile-an-hour damaging wind on September 6. Stalk lodging was affected by the cytoplasm (Table 33) with 38.7 and 50.3% lodged plants for the fertile

Table 33. Lodging as affected by male-sterility and population level and as a mean of 5 hybrids in 1969

Population (plants/a)	Percent lodging		
	Fertile	Sterile	Mean
18,000	22.5[a]	27.8[a]	25.1
24,000	32.8	43.8	38.3
30,000	53.5	57.8	55.6
36,000	38.8	66.0	52.4
54,000	46.0	56.5	51.3
Mean	38.7	50.3	44.5

[a]LSR = 9.1%.

and sterile genotypes respectively; however, this varied sharply from plot to plot as indicated by the high coefficient of variation (33.2%). All main and second order effects were significant for the lodging rating.

Harvest moisture varied significantly with the type of cytoplasm. Male-sterility as compared to the fertile enhanced the maturity, as reflected by the harvest moisture, by a mean 0.8%. Moisture at harvest was 19.1 and 17.8% at 18,000 plants per acre for the N and T cytoplasms respectively (Table 34); however, this difference is probably of negligible importance.

Table 34. Harvest moisture as affected by male-sterility and population level and as a mean of 5 hybrids in 1969

Population (plants/a)	Percent moisture		
	Fertile	Sterile	Mean
18,000	19.1[a]	17.8[a]	18.4
24,000	18.2	17.8	18.0
30,000	18.2	17.4	17.8
36,000	18.3	17.2	17.8
54,000	18.1	17.9	18.0
Mean	18.4	17.6	18.0

[a]LSR = 0.5%.

Shelling percentage was found to differ for the hybrid and for the hybrid by population interaction. B14 x 577 had a significantly smaller shelling percentage than the other 4 varieties as seen in Appendix Table 64. Male-sterility had little effect on the shelling percentage for the 5 hybrids or population levels used.

Beach 1969 (Experiment 5)

Four single-cross hybrids were planted June 17, 1969, at three population levels (18, 36, and 54,000 plants per acre) at Ames, Iowa. It was desired to see what potential effect cytoplasmic male-sterility could have in decreasing plant barrenness induced by an extremely late date of planting. Plant characteristics measured were grain yield, barrenness, silking date, and silking rate. Varieties XL-45, B14 x 577, and P3510 had reached physiological maturity (indicated by black layer formation) before a killing frost stopped metabolic activity; however, variety P3306 was harvested while immature with about 50 to 55% moisture content. The analysis of variance for each variable is presented in Appendix Table 65. All variables measured differed at the 1% level of probability for all main effects and second order interactions except silking rate which did not have a significant hybrid effect or hybrid by population interaction.

Grain yield was affected by the hybrids used as shown in Table 35. P3306 yielded significantly less at 36 and 54,000 plants per acre than the remaining 3 hybrids. Grain yield at 18,000 plants per acre was 4.1 bushels per acre less with the T than N cytoplasm; however, at 36,000 plants per acre male-sterility increased grain yield by 11.1 bushels per acre. Varieties varied considerably, however. P3510 yielded a nonsignificant 6.1

Table 35. Grain yield of 4 hybrids planted June 17, 1969, as affected by male-sterility and population level

Hybrid	Cyto- plasm	Grain yield in bushels/acre			
		18,000[a]	36,000[a]	54,000[a]	Mean
XL-45	F	124.6[b]	121.6	99.9	115.4
	S	122.1[b]	132.7	125.0	126.5
P3306	F	111.7	77.6	38.5	75.9
	S	107.1	110.2	70.7	96.0
B14 x 577	F	117.3	117.9	96.7	110.7
	S	111.2	124.5	108.0	114.6
P3510	F	120.7	127.1	103.1	117.0
	S	117.5	121.0	112.1	116.6
Mean	F	118.6[c]	111.0	84.6	104.7
	S	114.5[c]	122.1	103.7	113.4

[a]Plant population in plants per acre.

[b]LSR = 13.4 bu/a.

[c]LSR = 6.7 bu/a.

bushels per acre more at 36,000 plants per acre with the N than with the T cytoplasm while P3306 yielded 32.6 bushels per acre more with sterile cytoplasm. At 54,000 plants per acre, male-sterile cytoplasm was superior in yielding ability. Tcms hybrids yielded only slightly less at this high stand level than normal hybrids at 18,000 plants per acre for all varieties except P3306.

Plant barrenness was the major plant attribute affected by male-sterility as illustrated in Table 36. Surprisingly little, if any, plant barrenness was observed at 18,000 plants per acre. Male-sterility, on the other hand, decreased mean barrenness at 36,000 plants per acre by 8.0%

Table 36. Percent barrenness for 4 hybrids planted June 17, 1969, as affected by male-sterility and population level

Hybrid	Cyto-plasm	Barrenness in percent 18,000[a]	36,000[a]	54,000[a]	Mean
XL-45	F	0.0[b]	13.4	29.8	14.4
	S	0.0[b]	6.9	15.4	7.5
P3306	F	0.0	24.8	64.9	29.9
	S	0.0	4.1	31.4	11.8
B14 x 577	F	0.2	4.1	25.0	10.0
	S	0.0	3.3	12.5	5.3
P3510	F	0.2	9.3	23.6	11.3
	S	0.0	5.3	10.4	5.2
Mean	F	0.1[c]	12.9	35.8	16.4
	S	0.0[c]	4.9	17.4	7.4

[a]Plant population in plants per acre.

[b]LSR = 8.2%.

[c]LSR = 4.1%.

from the 12.9% of the normal cytoplasm. However, hybrids varied markedly with respect to plant barrenness at the various population levels. P3306 had 24.8% versus 4.1% and P3510 had 9.3% versus 5.3% barrenness for the N and T cytoplasms respectively at 36,000 plants per acre. At 54,000 plants per acre, the T cytoplasm decreased plant barrenness 12.5% for B14 x 577 to 32.5% for P3306 with a mean decrease of 18.4%.

The 75% silking date and rate of silking are shown in Table 37. Male-sterility decreased the days to obtain 75% silking by 0.9, 2.7, and 4.5 days at 18, 36, and 54,000 plants per acre respectively. Variety P3306 required 9.7 days longer at 54,000 plants per acre to reach 75% silking

Table 37. 75% silking date and rate of silking for 4 hybrids planted June 17, 1969, as affected by male-sterility and population levels

Hybrid	Cyto-plasm	75% silking date Days after July 1				Silking rate Days between 25-75% silking			
		P_1[a]	P_2[a]	P_3[a]	Mean	P_1[a]	P_2[a]	P_3[a]	Mean
XL-45	F	46.8[b]	50.7	54.0	50.5	1.3[d]	4.2	7.3	4.2
	S	46.3[b]	46.9	49.3	47.5	1.3[d]	1.4	2.6	1.7
P3306	F	52.0	58.0	65.5	58.4	1.5	4.7	7.5	4.6
	S	51.4	53.5	55.8	53.6	1.5	1.8	2.3	1.8
B14 x 577	F	50.3	53.2	55.9	53.1	1.8	3.4	3.8	3.0
	S	48.7	52.1	54.2	51.6	1.2	3.2	3.3	2.5
P3510	F	49.4	52.7	54.3	52.1	2.1	4.0	4.5	3.5
	S	48.4	51.1	51.9	50.5	1.6	2.6	2.5	2.2
Mean	F	49.6[c]	53.6	57.3	53.5	1.7[e]	4.1	5.8	3.8
	S	48.7[c]	50.9	52.8	50.8	1.4[e]	2.2	2.6	2.1

[a]Population in plants/acre: P_1 = 18,000, P_2 = 36,000, P_3 = 54,000.

[b]LSR = 2.3 days.

[c]LSR = 1.2 days.

[d]LSR = 1.7 days.

[e]LSR = 0.8 days.

with N than with T cytoplasm. This delayed silking was reflected in the 32.5% greater barrenness by the normal genotype. On the other hand, the Tcms of the hybrid B14 x 577 required 1.7 days less to reach 75% silking than the fertile genotype and is reflected by a difference of only 12.5% greater barrenness by the normal genotype.

The observed earliness by male-steriles was the result of an average earlier silk emergence of 0.6, 0.6, and 1.3 days and a faster silking rate of 0.3, 1.9, and 3.2 days at 18, 36, and 54,000 plants per acre respectively (Table 37). The silking rate was delayed 2.4 and 0.8 days by increasing the stand level from 18 to 36,000 plants per acre for the N and T cytoplasms respectively. This marked uniformity of silking for Tcms hybrids between the 2 populations is reflected in the reduced barrenness for Tcms hybrids noted above.

Population by Row Spacing Study

Single-cross hybrids with the N and T cytoplasms were planted at Ames and Madrid, Iowa, during 1968 and 1969 at various row spacings but including at least the 20-inch versus 40-inch row spacing comparison. Interest in the effect of row spacing on grain yield has recently received considerable attention; however, it was not the purpose of these experiments to substantiate the row spacing effect but to investigate the interaction of row spacing with high (45 to 54,000 plants per acre) plant densities. It was hypothesized that possibly light flux density or gaseous exchange for the ear leaf under these very high plant densities and narrow rows might become a more important factor, due to the "sealing off" of the canopy by upper leaves, than interplant competition within wider spaced rows. Climatic conditions were similar to those discussed briefly in the previous section.

Beach 1968 (Experiment 6)

Two single-cross commercial hybrids, XL-45 and SX 29, with both the N and T cytoplasms were planted in 5 row spacings (10, 20, 30, 40, and 60 inches) at a normal, high, and extremely high plant population (15, 30, and 45,000 plants per acre) at Ames, Iowa, in 1968. Five plant characteristics including combine grain yield, barrenness, kernel weight, 75% silking date, and silking rate were measured. Mean plant response and the analysis of variance for the 5 variables measured are presented in Appendix Tables 66 and 67 respectively. Furthermore, the light flux intercepted at the ear height and total light flux intercepted were measured for all treatments of variety SX29. Analyses of variance for these measurements are presented in Appendix Table 68.

Combine grain yield was influenced by row spacing at greater than the 10% level of probability; however, it was the 60-inch rows that yielded significantly less. No difference was found between the 10- thru 40-inch row spacings. The interaction of row spacing with population, the major point of interest, was nonsignificant as is readily seen in Table 38.

Table 38. Combine grain yield for 5 row spacings as affected by population level and as a mean of the fertile and sterile of 2 hybrids in 1968

Row spacing (inches)	Grain yield in bushels per acre			
	15,000[a]	30,000[a]	45,000[a]	Mean
10	122.0[b]	115.6	96.9	111.5
20	125.3	118.1	91.8	111.7
30	125.9	119.9	97.8	114.5
40	125.6	116.0	97.1	112.9
60	110.1	101.5	80.8	97.5
Mean	121.8	114.2	92.8	109.6

[a]Population in plants per acre.

[b]LSR between row spacings = 10.0 bu/a.

Combine grain yield was slightly higher for 45,000 plants per acre for 30- and 40-inch rows. None of these differences were significant. Analyses of variance for the remaining measured plant characteristics indicated no significant differences for row spacings or any of the interactions with row spacing; therefore, all further data for this experiment will be reported as a mean of the 5 row spacings.

Combine grain yield differed at the 1% level of probability for hybrids, population levels, cytoplasms, and the interaction, hybrid by population. Male-sterility increased the combine grain yield by a mean 9.9 bushels per acre as shown in Table 39. Grain yield was 5.3, 14.4, and 10.1

Table 39. Combined grain yield for 2 varities as affected by male-sterility and population levels and as a mean of 5 row spacings in 1968

Hybrid	Cyto-plasm	Grain yield in bushels per acre 15,000[a]	30,000[a]	45,000[a]	Mean
SX 29	F	122.2[b]	101.9	71.1	98.4
	S	128.8[b]	115.3	89.3	111.1
XL-45	F	116.1	112.2	104.5	110.9
	S	120.0	127.5	106.5	118.0
Mean	F	119.1[c]	107.0	87.8	104.7
	S	124.4[c]	121.4	97.9	114.6

[a]Population in plants per acre.

[b]LSR = 8.0 bu/a.

[c]LSR = 5.6 bu/a.

bushels per acre higher with T than N cytoplasm at 15, 30, and 45,000 plants per acre which was reflected in a significant cytoplasm by population interaction at the 10% level. Similar significance was noted for the hybrid by cytoplasm interaction mainly due to the relative small effect of the T cytoplasm at 45,000 plants per acre for the variety XL-45.

Plant barrenness was cytoplasmically affected, especially for variety SX 29, as illustrated in Table 40. Barrenness for the hybrid SX29 was

Table 40. Percent barrenness for 2 varieties as affected by male-sterility and population levels and as a mean of 5 row spacings in 1968

Hybrid	Cyto-plasm	Percent barren plants 15,000[a]	30,000[a]	45,000[a]	Mean
SX 29	F	1.8[b]	17.3	45.5	21.5
	S	1.0[b]	15.0	22.2	12.7
XL-45	F	0.0	8.3	20.8	9.7
	S	0.3	6.9	24.3	10.5
Mean	F	0.9[c]	12.8	33.1	15.6
	S	0.6[c]	10.9	23.2	11.6

[a]Population in plants per acre.

[b]LSR = 6.6%.

[c]LSR = 4.7%.

reduced slightly at 30,000 plants per acre and markedly at 45,000 plants per acre by male-sterility; however, the Tcms of the variety XL-45 at the highest stand level was slightly higher in barrenness than the fertile. This resulted in highly significant hybrid by cytoplasm and hybrid by cytoplasm by population interactions. All main effects significantly influenced plant barrenness. On the average, male-sterile cytoplasm reduced plant barrenness by 0.3, 1.9, and 9.9% at 15, 30, and 45,000 plants per acre respectively. The difference at 30,000 plants per acre was not large enough to account for the noted yield increase by the Tcms hybrids.

Kernel weight was reduced significantly with T cytoplasm by a mean 0.6 grams per 100 seed. Mean weight per 100 seed was 26.9, 24.3, and 24.2 grams at 15, 30, and 45,000 plants per acre respectively (Table 41). Population stress decreased the 100 seed weight 2.6 grams by increasing the population from 15 to 30,000 plants per acre, but another similar population increase had little effect on kernel size.

Table 41. Kernel weight for 2 varities as affected by male-sterility and population level and as a mean of 5 row spacings in 1968

Hybrid	Cyto-plasm	Weight per 100 seeds in grams			
		15,000[a]	30,000[a]	45,000[a]	Mean
SX 29	F	27.5[b]	24.7	24.4	25.5
	S	27.7[b]	23.9	23.7	25.1
XL-45	F	26.6	24.7	24.8	25.4
	S	25.8	23.9	23.9	24.5
Mean	F	27.1[c]	24.7	24.6	25.4
	S	26.7[c]	23.9	23.8	24.8

[a]Population in plants per acre.

[b]LSR = 1.0 grams.

[c]LSR = 0.7 grams.

Male-sterility significantly affected the days to 75% silking. The mean 75% silking date was 27.4 and 25.8 days after July 1 for the N and T cytoplasms respectively. The silking date was decreased 3.1 and 0.1 days for the Tcms of SX 29 and XL-45 respectively leading to a significant interaction between the hybrid and cytoplasm. The type of cytoplasm also interacted with the stand level. Male-sterility decreased the 75% silking date by -0.1, 2.3, and 2.7 days at 15, 30, and 45,000 plants per acre respectively. Variety had a strong influence on the silking date response as seen in Table 42.

Table 42. 75% silking date for 2 varieties as affected by male-sterility and population levels and as a mean of 5 row spacings in 1968

Hybrid	Cyto-plasm	75% silking date 15,000[a]	30,000[a]	45,000[a]	Mean
SX 29	F	7-27.4[b]	8-2.3	8-6.2	8-1.6
	S	7-26.3[b]	7-29.3	8-2.3	7-29.5
XL-45	F	7-18.7	7-21.9	7-25.8	7-22.1
	S	7-20.2	7-21.3	7-24.7	7-22.0
Mean	F	7-23.1[c]	7-27.6	8-0.5	7-27.4
	S	7-23.2[c]	7-25.3	7-28.8	7-25.8

[a]Population in plants per acre.

[b]LSR = 1.2 days.

[c]LSR = 0.9 days.

The silking rate differed significantly for hybrids, cytoplasms, and population levels and their two-way interactions. Male-sterility reduced the mean number of days between 25 and 75% silking by 1.0 days; however, variety SX 29 silked 1.6 days faster whereas XL-45 silked only 0.4 days faster with the T as compared to N cytoplasm. The mean silking rate was 0.2, 1.3, and 1.4 days less for Tcms hybrids than their fertile counterparts at 15, 30, and 45,000 plants per acre respectively. This caused a population by cytoplasm interaction at greater than the 10% level. Hybrids differed in their silking rate response to population level when the silking rate was compared between the fertile and sterile counterparts as shown in Table 43.

Table 43. Silking rate of 2 hybrids as affected by male-sterility and population levels and as a mean of 5 row spacings in 1968

Hybrid	Cyto-plasm	Days between 25 and 75% silking			
		15,000[a]	30,000[a]	45,000[a]	Mean
SX 29	F	2.8[b]	6.2	7.3	5.4
	S	2.1[b]	3.7	5.7	3.8
XL-45	F	2.0	3.2	6.1	3.8
	S	2.3	3.1	4.9	3.4
Mean	F	2.4[c]	4.7	6.7	4.6
	S	2.2[c]	3.4	5.3	3.6

[a]Population in plants per acre.

[b]LSR = 0.7 days.

[c]LSR = 0.5 days.

Ear height and total light flux intercepted was measured for SX 29 for all row spacings, population levels, and cytoplasm types. Analyses of variance indicated row spacing and population level to significantly affect both the ear height and total light intercepted. Total light flux intercepted was lower for 60-inch rows than the other row spacings. In general, no difference was noticed in total light flux intercepted in 10-, 20-, 30-, or 40-inch rows (Table 44). Light penetration decreased as the population level increased with the mean light intercepted at 85.0, 90.4, and 93.2% for 15, 30, and 45,000 plants per acre respectively. The middle stand level had a slightly lower light penetration for 10-inch than 40-inch rows;

Table 44. Percent light flux intercepted for SX 29 as affected by row spacing and population level and as a mean of fertile and sterile counterparts in 1968

Row spacing (inches)	% of total light intercepted				% light intercepted above the ear			
	P_1[a]	P_2[a]	P_3[a]	Mean	P_1[a]	P_2[a]	P_3[a]	Mean
10	87.8[b]	96.2	97.7	93.9	71.8[c]	84.5	92.7	83.0
20	88.8[b]	95.2	98.2	93.9	66.2[c]	75.0	84.2	75.2
30	88.0[b]	94.8	96.5	92.1	63.2[c]	86.5	88.0	79.3
40	87.8[b]	94.8	97.8	93.0	68.8[c]	78.0	80.8	75.8
60	73.5[b]	71.8	75.5	73.5	49.8[c]	56.0	65.3	56.8
Mean	85.0	90.4	93.2	89.4	63.9	76.0	82.9	76.0

[a]Population levels in plants per acre: P_1 = 15,000, P_2 = 30,000, P_3 = 45,000.

[b]LSR between the row spacings = 7.2%.

[c]LSR between the row spacings = 9.6%.

however, this difference was by no means significant. In general, light flux above the ear decreased as the row spacing was narrowed; however, 20-inch rows deviated from this trend. The 20- and 40-inch rows were similar in the amount of light intercepted above the ear while 10- and 30-inch rows had a lower light flux penetration than the 20- or 40-inch rows at 30 and 45,000 plants per acre. The amount of light intercepted above the ear also increased with population as one would expect.

Ear height for variety SX 29 was not significantly affected by the cytoplasm type or stand density. Row spacing was found to affect ear height at greater than the 10% level of probability with 30-inch rows having the highest ear (Table 45). Increasing the population from 15 to 30 to 45,000 plants per acre caused the ear height to decrease in 30-inch rows, increase, and then decrease in 40-inch rows while it increased in 10-, 20-, and 60-inch rows. This resulted in a significant row spacing by population interaction, but the reason for this interaction is unclear.

Table 45. SX 29 ear height as affected by row spacing and population level and as a mean of the fertile and sterile cytoplasm in 1968

Row spacing (inches)	Ear height in inches 15,000[a]	30,000[a]	45,000[a]	Mean
10	57.5	58.8	59.5	58.6
20	60.3	60.0	61.0	60.4
30	63.5	62.8	59.8	62.0
40	58.8	62.0	60.0	60.3
60	57.3	59.5	60.3	59.0
Mean	59.4	60.6	60.1	60.0

[a]Population in plants per acre.

Madrid 1968 (Experiment 7)

Ten single-cross corn hybrids, each with the fertile and sterile comparison, were planted at Madrid, Iowa, in 1968 in 20- and 40-inch row spacings. Two population levels, normal and high (18 and 54,000 plants per acre), were used. If a row spacing by high population interaction on yield could be shown for the 2 varieties in Experiment 6, it appeared desirable to test the effect for several hybrids. Six plant characteristics were measured including grain yield, ears per 100 stalks, ear weight, kernel weight, 75% silking date, and silking rate. Mean plant response and the analysis of variance for each variable measured are presented in Appendix Tables 69 and 70 respectively.

Similar to the previous experiment, grain yield was not significantly affected by row spacing at the high plant population. Grain yield was 128.9 and 130.0 bushels per acre for 20- and 40-inch rows respectively (Table 46) but is far from being significant. Furthermore, grain yield did not differ for any two- or three-way interactions with row spacing. Thus, all further data will be presented as a mean of the 2 row spacing treatments.

Table 46. Grain yield for 2 row spacings as affected by population level and male-sterility and as a mean of 10 varieties in 1968

Row spacing	Cyto-plasm	Grain yield in bushels per acre		
		18,000[a]	54,000[a]	Mean
20"	F	133.0[b]	107.2	120.1[c]
	S	149.5[b]	126.0	137.7[c]
40"	F	138.7	109.8	124.2
	S	143.8	128.1	135.9
Mean	F	135.9[c]	108.5	122.1
	S	146.6[c]	127.1	136.8

[a]Population in plants per acre.

[b]LSR = 8.1 bu/a.

[c]LSR = 5.8 bu/a.

Grain yield for the 10 hybrids as affected by male-sterility and population level is presented in Table 47. Five Tcms hybrids (UH 138, P3510, SX 29, PX610, and XL-45) yielded significantly higher than their fertile counterparts with a mean increase of 14.6 bushels per acre (11.3%). Two

Table 47. Grain yield for 10 hybrids as affected by male-sterility and population level and as a mean of 2 row spacings in 1968

	Grain yield in bushels per acre			
	18,000[a]		54,000[a]	
Hybrid	Fertile	Sterile	Fertile	Sterile
A619 x A632	145.1[b]	152.5[b]	124.4[b]	140.9[b]
UH 138	131.8	145.0	116.4	137.8
P3510	133.3	167.3	86.4	129.9
336 x 025	111.4	113.5	92.9	104.5
P3306	163.4	170.5	130.4	136.8
B14 x 577	143.0	148.5	120.3	126.3
336 x 029	124.9	130.6	118.1	113.1
SX 29	130.8	134.6	72.9	105.5
PX610	136.3	156.6	111.1	137.3
XL-45	139.1	147.4	112.0	138.6
Mean	135.9	146.6	108.5	127.1

[a]Population in plants/acre.

[b]LSR = 18.2 bu/a.

Tcms hybrids had significantly higher yields at the normal stand level whereas 6 Tcms hybrids were significantly higher grain yielders at the high stand level than their normal counterparts. This produced significant hybrid by cytoplasm and population by cytoplasm interactions. The typical variation in population tolerance of the diverse hybrids was noted in a significant population by hybrid interaction.

Plant barrenness differed at the 1% level of probability for the hybrid, population level, cytoplasm type, and their two- and three-way interactions. Mean barrenness was 2.7% versus 0.8% at 18,000 plants per acre and 33.5% versus 24.0% at 54,000 plants per acre for the N and T cytoplasms respectively. Barrenness, noted at the normal stand density for the N cytoplasm, was caused mainly by the hybrid P3510 as seen in Table 48. The reason for

Table 48. Plant barrenness of 10 hybrids as affected by male-sterility and population level and as a mean of 2 row spacings in 1968

	Percent barren plants			
	18,000[a]		54,000[a]	
Hybrid	Fertile	Sterile	Fertile	Sterile
A619 x A632	0.0[b]	0.0[b]	27.6[b]	23.2[b]
UH 138	5.2	4.1	32.0	22.1
P3510	18.5	0.5	51.3	31.4
336 x 025	4.0	0.0	31.1	22.7
P3306	0.0	1.5	31.4	28.1
B14 x 577	0.0	0.0	33.9	23.2
336 x 029	0.0	0.0	23.5	21.4
SX 29	0.0	1.4	36.7	29.5
PX610	0.0	0.7	32.2	18.9
XL-45	0.0	0.0	35.4	19.3
Mean	2.7	0.8	33.5	24.0

[a]Population in plants per acre.

[b]LSR = 8.1%.

this particularily high barrenness is unknown but was probably the leading cause of the significant hybrid by population by cytoplasm interaction obtained. Tcms hybrids had a mean 9.5% less barrenness at 54,000 plants per acre. Several genotypes produced second ears at the normal population as shown in Appendix Table 69 by the ears per 100 stalks. A greater number of second ears accounted for the yield advantage of steriles noted at the normal population.

Kernel weight was significantly affected by the cytoplasm type giving a mean 0.3 grams per 100 seed decrease with the T as compared to N cytoplasm. Hybrids differed in their response to the type of cytoplasm (Table 49). Kernel weight of the varieties A619 x A632, P3510, and XL-45

Table 49. Kernel weight for 10 hybrids at 2 population levels as affected by male-sterility and as a mean of 2 row spacings in 1968

	Weight in grams/100 seed			
	18,000[a]		54,000[a]	
Hybrid	Fertile	Sterile	Fertile	Sterile
A619 x A632	29.1[b]	27.8[b]	27.5[b]	27.8[b]
UH 138	25.0	24.7	23.4	23.7
P3510	28.5	27.2	27.9	27.6
336 x 025	23.2	22.2	20.5	20.2
P3306	32.3	32.1	31.0	32.0
B14 x 577	29.4	28.6	26.9	24.4
336 x 029	23.9	23.8	19.9	18.3
SX 29	27.9	28.0	23.4	25.1
PX610	28.4	29.3	26.9	27.8
XL-45	27.4	26.3	25.5	23.9
Mean	27.5	27.0	25.4	25.3

[a]Population in plants per acre.

[b]LSR = 1.0 grams.

were decreased significantly at 18,000 plants per acre with sterile cytoplasm whereas the varieties 336 x 029, B14 x 577, and XL-45 decreased and SX 29 increased kernel weight significantly at the high population. The population by cytoplasm interaction was nonsignificant, but the majority of the mean decrease in kernel weight was at the normal population.

The remaining yield component, ear weight, differed at the 1% level of probability for the hybrid, population level, and their interaction, as would be expected from the diversity of the hybrids and the variation in population tolerance of the genotypes used. The Tcms versions of varieties A619 x A632 and SX 29 produced significantly lighter ears than their normal counterparts whereas the Tcms versions of varieties UH 138 and PX610 produced significantly larger ears than their normal counterparts causing a significant hybrid by cytoplasm interaction. P3306 Tcms had a significantly smaller ear weight at 54,000 plants per acre whereas 5 varieties were significantly different at the normal population (Table 50). This

Table 50. Ear weight for 10 hybrids at 2 population levels as affected by male-sterility and as a mean of 2 row spacings in 1968

	Ear weight in grams per ear			
	18,000[a]		54,000[a]	
Hybrid	Fertile	Sterile	Fertile	Sterile
A619 x A632	213[b]	197[b]	112[b]	108[b]
UH 138	189	225	104	114
P3510	227	227	115	116
336 x 025	165	157	79	89
P3306	234	250	122	109
B14 x 577	178	175	107	98
336 x 029	174	156	96	86
SX 29	183	193	89	91
PX610	201	220	100	103
XL-45	192	189	100	103
Mean	195	200	103	101

[a]Population in plants per acre.

[b]LSR = 14.4 grams.

probably caused the significant hybrid by population by cytoplasm interaction observed in the analysis.

The silking date and the silking rate varied with the hybrid, population level, and cytoplasm type. Male-sterility decreased the 75% silking date by 0.6 and 4.2 days at the normal and high plant densities respectively (Table 51). The silking rate accounted for 0.3 days later 75%

Table 51. 75% silking date and rate of silking for 10 hybrids as affected by male-sterility and population level and as a mean of 2 row spacings in 1968

	Days after July 1				Silking rate (days)			
	18,000[a]		54,000[a]		18,000[a]		54,000[a]	
Hybrid	Fertile	Sterile	Fertile	Sterile	Fertile	Sterile	Fertile	Sterile
A619 x A632	17.8[b]	17.6[b]	27.4[b]	22.5[b]	1.6[c]	1.5[c]	9.9[c]	5.6[c]
UH 138	20.3	19.3	32.1	24.8	2.9	1.9	9.8	4.9
P3510	24.1	22.7	36.3	33.4	2.6	2.6	10.9	10.4
336 x 025	18.8	19.1	22.3	21.3	1.8	1.9	4.1	2.9
P3306	24.5	24.2	33.7	30.2	2.4	2.6	7.8	6.2
B14 x 577	24.3	22.9	31.5	27.9	2.7	2.2	9.1	5.4
336 x 029	18.7	18.9	24.0	20.8	2.0	2.2	6.4	3.8
SX 29	24.9	24.2	34.6	29.3	2.3	1.6	8.7	4.8
PX610	21.2	20.3	27.8	23.7	3.2	2.6	7.1	3.9
XL-45	19.1	19.2	28.6	22.4	2.4	2.4	9.9	4.7
Mean	21.4	20.8	29.8	25.6	2.4	2.1	8.4	5.3

[a]Population in plants per acre.

[b]LSR = 2.3 days.

[c]LSR = 2.3 days.

silking at the normal population whereas it explains 3.1 days later 75% silking date at the high population; therefore, Tcms hybrids had silk emergence 0.3 and 1.1 days earlier at the 2 stand levels respectively. Significant differences in the silking rate or date between the N and T cytoplasms did not occur at the normal population for any hybrid, but all varieties except 336 x 025 took a significantly greater number of days to obtain 75% silking and 7 of the 10 hybrids silked faster at the high plant density with the T cytoplasm.

Grain yield as mentioned previously was unaffected by row spacing, but it is interesting to note that row spacing significantly affected the ears per 100 stalks, the 75% silking date, and the silking rate (Appendix Table 70). A larger number of ear-bearing plants in the 40-inch rows was reflected in the nonsignificant 2 bushels per acre higher grain yield in 40-inch rows than the 20-inch rows. The 75% silking date was 0.7 days earlier at 18,000 plants per acre and 2.7 days earlier at 54,000 plants per acre in 40-inch rows than in 20-inch rows. The silking rate accounted for 2.6 days of the earlier 75% silking date.

Madrid 1969 (Experiment 8)

Two single-cross hybrids (SX 29 and P3306) with the fertile and sterile counterparts were planted in 3 row spacings (10-, 20-, and 40-inch rows) at Madrid, Iowa, in 1969. It was desired to further substantiate the increased population tolerance with male-sterility and to investigate further the effect row spacing had at very high population levels; therefore, 5 population levels (15, 22.5, 30, 37.5, and 45,000 plants per acre) were used. Grain yield, barrenness, ear weight, 75% silking date, and the silking rate were the plant characteristics measured. Mean plant response for each variable is presented in Appendix Table 71. Data from this section should be viewed with caution for 2 reasons. First, 2, 4-dichlorophenoxy-acetic acid was sprayed on the 10- and 20-inch rows June 20 for broadleaf weed control. Plants sprayed were noticeably more "brittle" from the spray application. A 40 to 50 mile-an-hour wind on June 26 caused severe damage in the form of plant breakage by the "brittle" plants reducing the desired populations. Secondly, a 90 mile-an-hour wind was sustained on September 6 which caused severe plant lodging, especially in the 10- and 20-inch rows, reducing the late season dry matter accumulation. Therefore, the data will be discussed on the 40-inch rows only. Analysis of variance for each variable measured for the 40-inch row spacing is presented in Appendix Table 72.

Contrary to all previous experiments, the type of cytoplasm as a mean of the 2 varieties had no consistent effect on grain yield at any population level as illustrated in Table 52. However, as indicated by the highly significant hybrid by cytoplasm interaction, the hybrid markedly affected the grain yield response with the different cytoplasms. The Tcms version of SX 29 increased grain yield 10.9 bushels per acre while the Tcms version of P3306 decreased grain yield 9.1 bushels per acre relative to the fertile counterpart. Population level had a highly significant effect on grain yield, but the population as a mean of the 2 hybrids did not interact with the cytoplasm. SX 29 yielded higher with T cytoplasm at all populations, but P3306 yielded higher with N cytoplasm at all populations. Only at the high stand density for both varieties was this response significant by Duncan's multiple range test. In general SX 29 produced similar yield results as previous experiments herein reported. Variety P3306, on the

Table 52. Grain yield for 2 hybrids in 40" row spacing as affected by male-sterility and population level in 1969

Population (plants/a)	Grain yield in bushels/acre					
	SX 29		P3306		Mean	
	Fertile	Sterile	Fertile	Sterile	Fertile	Sterile
15,000	148.9[a]	156.8[a]	162.2[a]	150.2[a]	155.6[b]	153.5[b]
22,500	161.2	172.0	184.3	176.0	172.7	174.0
30,000	151.4	159.0	179.1	175.2	165.3	167.1
37,500	131.3	143.3	159.3	153.4	145.3	148.3
45,000	121.2	137.2	149.2	131.8	135.2	134.5
Mean	142.8	153.7	166.8	157.3	154.8	155.5

[a]LSR = 15.0 bu/a.

[b]LSR = 10.6 bu/a.

other hand, is in direct contrast to the yield pattern for T cytoplasm in these experiments.

Ears per 100 stalks showed a somewhat different pattern than grain yield. Male-sterility decreased plant barrenness significantly for SX 29 but not for P3306 as illustrated in Table 53. The significant population by sterility interaction was caused mainly by a larger number of double ears for the normal hybrids at 15,000 plants per acre and a lower percent barrenness at 37,500 plants per acre for Tcms hybrids relative to its normal counterpart. The number of harvestable ears accounted for the yield advantage of the Tcms of SX 29 at all population levels except 18,000 plants per acre whereas harvestable ears accounted for the noted yield differences at 15,000 plants per acre only for the Tcms of P3306.

Table 53. Ears per 100 stalks for 2 hybrids in 40" row spacing as affected by male-sterility and population level in 1969

Population (plants/a)	Ears per 100 stalks					
	SX 29		P3306		Mean	
	Fertile	Sterile	Fertile	Sterile	Fertile	Sterile
15,000	122.5[a]	119.6[a]	112.7[a]	105.9[a]	117.6[b]	112.7[b]
22,500	95.2	100.0	98.1	96.8	96.6	98.4
30,000	89.8	93.9	89.1	93.1	89.5	93.5
37,500	76.2	88.0	76.8	86.2	76.5	87.1
45,000	71.6	82.0	68.1	67.5	69.9	74.8
Mean	91.1	96.7	89.0	90.0	90.0	93.3

[a]LSR = 9.3%.

[b]LSR = 6.6%.

The component of yield which explains the yield difference unaccounted for by ears per 100 stalks was the ear weight. SX 29 had a significantly lighter ear than P3306 as shown in Table 54. Variety SX 29's ear weight increased 2 grams per ear whereas P3306's ear weight decreased 11 grams per ear with the T cytoplasm. This resulted in a highly significant hybrid by cytoplasm interaction. Population level drastically reduced the mean ear weight. The Tcms of variety SX 29 at 15,000 plants per acre approached significance for a larger ear which accounted for the slightly larger yield noted for this population whereas the ear weight for the Tcms of P3306 at the same population decreased slightly. Ear weight of P3306 at 37,500 plants per acre was significantly less with T than N cytoplasm. This sig-

Table 54. Ear weight for 2 hybrids in 40" row spacing as affected by male-sterility and population level in 1969

Population (plants/a)	Ear weight in grams per ear					
	SX 29		P3306		Mean	
	Fertile	Sterile	Fertile	Sterile	Fertile	Sterile
15,000	207[a]	222[a]	244[a]	240[a]	225[b]	231[b]
22,500	191	194	212	205	202	200
30,000	143	143	171	159	157	151
37,500	117	110	141	120	129	115
45,000	96	95	124	110	110	103
Mean	151	153	178	167	164	160

[a]LSR = 19.8 grams.

[b]LSR = 14.0 grams.

nificantly smaller ear by the Tcms hybrid reduced the grain yield even though it had more harvestable ears.

The 75% silking date was significantly influenced by the population level only. Increasing the population from 15 to 45,000 plants per acre delayed the mean silking date by 5.2 days (Table 55). Male-sterility decreased the 75% silking date by 0.6 days which approached the 5% level of statistical significance. An interaction between the population level or hybrid with the cytoplasm type, as found in most of the previous experiments, was not detectable in this exoeriment.

The days between 25 and 75% silking was significantly shorter for Tcms hybrids and lower population levels. The hybrid SX 29 accounted for all the mean difference in the silking rate between the N and T cytoplasms as

Table 55. 75% silking date for 2 hybrids in 40" row spacing as affected by male-sterility and population level in 1969

Population (plants/a)	75% silking date (days after July 1)					
	SX 29		P3306		Mean	
	Fertile	Sterile	Fertile	Sterile	Fertile	Sterile
15,000	28.8[a]	28.8[a]	29.5[a]	29.2[a]	29.2[b]	29.0[b]
22,500	28.7	28.0	30.7	29.7	29.7	28.8
30,000	30.3	29.8	32.7	31.8	31.5	30.8
37,500	32.8	32.4	33.8	32.9	33.3	32.7
45,000	33.6	32.4	35.6	35.6	34.6	34.0
Mean	30.8	30.3	32.4	31.8	31.6	31.0

[a]LSR = 2.0 days.
[b]LSR = 1.4 days.

Table 56. Silking rate for 2 hybrids in 40" row spacing as affected by male-sterility and population level in 1969

Population (plants/a)	Days between 25 and 75% silking					
	SX 29		P3306		Mean	
	Fertile	Sterile	Fertile	Sterile	Fertile	Sterile
15,000	3.3[a]	2.4[a]	2.7[a]	2.6[a]	3.0[b]	2.5[b]
22,500	3.4	2.4	2.8	2.8	3.1	2.6
30,000	4.3	2.3	3.0	3.3	3.7	2.8
37,500	5.8	4.7	4.1	3.6	5.0	4.1
45,000	4.8	4.1	3.6	3.9	4.2	4.0
Mean	4.3	3.2	3.2	3.2	3.8	3.2

[a]LSR = 1.4 days.
[b]LSR = 1.0 days.

shown in Table 56. Variety P3306 did not differ significantly for the silking rate at any population level whereas the Tcms of SX 29 was significantly faster silking at 30,000 plants per acre with the silking rates at 22.5 and 37,500 plants/acre approaching significance as tested by Duncan's multiple range test.

DISCUSSION

Cytoplasm by Population Study

Several investigations have shown cytoplasmic male-sterile single-cross hybrids to yield superior to their fertile counterparts. Chinwuba et al. (1961) found a single genotype to yield 22.2 bushels per acre higher with the T than with the N cytoplasm at 27,500 plants per acre whereas only 11.6 bushels per acre at 13,250 plants per acre. Schwanke (1965) reported a mean 24.4% sterile yield advantage for 6 single-cross hybrids at 32,000 plants per acre with 4 hybrids having significant yield increases. On the other hand, Duvick (1965) showed no consistent effect by the type of cytoplasm on the yield of 67 nonrestored three-way crosses at a normal plant density. This is in agreement with many earlier authors who studied various single-cross hybrids (Everett, 1960; Josephson and Kincer, 1962; Noble and Russell, 1963; Marquez-Sanchez, 1964). It was the purpose of this study to further elicit some of the effects cytoplasmic male-sterility had on the yield and barrenness response of several single-cross hybrids under population stress conditions.

The hybrids included in this study differed markedly in their response to cytoplasmic male-sterility. For 44 comparisons (sum of the hybrids used in 1967, 1968, and 1969) between the N and T cytoplasms, Tcms genotypes outyielded their normal counterparts in 37 comparisons (19 significantly). Normal cytoplasm yielded significantly higher than the T cytoplasm in only 2 comparisons. The yield of the intolerant variety 071 x 705 was increased significantly by Tcms whenever included as a test hybrid whereas the tolerant hybrid B14 x 577 across all 5 experiments had very little, if any, differential yield with the type of cytoplasm. Similar results were obtained with the hybrids 425 x 091 and 155 x 526. However, significant cytoplasmic effects on the grain yield of the population tolerant hybrids A619 x A632, PX610, and XL-45 were noted in several experiments. The yields of the 2 early genotypes, 336 x 029 and 336 x 025, were unaffected by male-sterility in 1968, and UH 108 was slightly increased in 1969, whereas the yields of 336 x 025 and UH 108 were significantly reduced by male-sterility in 1967. The variety P3510 gave little response to sterility in 1967 whereas in 1968 it gave the largest response (48.8%); response in 1969 was a more modest 11.5%. These varieties exemplify the hybrid by environment by cytoplasm interaction that would have been obtained if a combined analysis could have been computed. This agrees with the findings of several other workers (Grogan, 1956; Everett, 1960; Marquez-Sanchez, 1964; Duvick, 1958, 1965).

Male-sterility generally increased a hybrid's tolerance to population stresses. As a mean of 10 hybrids in 1969, Tcms hybrids yielded a nonsignificant 2.3 bushels per acre greater than the 152.6 bushels per acre yielded by their fertile counterparts at 18,000 plants per acre. On the other hand, Tcms hybrids yielded 17.3 bushels per acre more than the 141.2 bushels per acre yielded by their fertile counterparts at 36,000 plants per acre. Eight of the 10 hybrids at the high population yielded substantially higher with sterile cytoplasm. Similar results were noted for the 5 population levels utilized in another experiment conducted in 1969. At 18, 24, and 54,000 plants per acre, little differences in yield were noted, but at 30 and 36,000 plants per acre, significant increases in yield were obtained with Tcms hybrids. This clearly implicates an interaction between the cytoplasm and population level.

Grain yield as affected by male-sterility showed a marked difference at 18,000 plants per acre in 1968 than that noted in 1969. Mean grain yield was 12.4% higher for T as compared to N cytoplasm. This yield advantage was due primarily to larger ear weights by some Tcms hybrids, however, some Tcms hybrids had a greater number of second ears. Tcms hybrids at 36,000 plants per acre yielded comparable to the normal population whereas normal cytoplasmic hybrids exhibited substantial yield decreases at the high plant density. Grain yield for the late planting experiment in 1969 was reduced a mean 4.1 bushels per acre by the T as compared to the N cytoplasm at 18,000 plants per acre while grain yield was increased 11.1 bushels per acre at 36,000 plants per acre.

The previous results implicate a strong interaction between the cytoplasm and population with the yield advantage for Tcms hybrids at normal plant densities highly dependent on environmental conditions whereas the yield advantage for Tcms hybrids at high plant densities was consistent across environments. This cytoplasm by population by environment interaction has not been generally reported but agrees with the predication of Grogan (1956) that Tcms might have a yield advantage under a stress condition such as above optimum plant populations.

Tcms hybrids at 54,000 plants per acre did not significantly outyield their fertile counterparts at one location in 1969 whereas Tcms hybrids significantly outyielded their fertile counterparts at another location in 1969 and in 1968. The variableness in yield at this population indicates that the factors controlling the response to male-sterility are not fully understood.

Environmental factors such as light, moisture, and nutrients are known to limit the maximum yield potential of a given hybrid. It is interesting to note the plateau in grain yield observed at 24, 30, and 36,000 plants per acre for the mean Tcms hybrid of Experiment 5. The mean of the normal hybrids, on the other hand, reached a maximum yield around 24,000 plants per acre and declined thereafter mainly due to increasing plant barrenness. Apparently, male-sterile cytoplasm decreased the adverse effects of above optimum population such that plant barrenness was no longer limiting further grain yield; however, some factor (possibly environmental) imposed a "ceiling" on the availability of photosynthates for the developing ear thereby reducing the ear weight for each increase in plant density. Without this limitation, the Tcms hybrids should have shown the typical optimum population response generally noted for single-eared genotypes.

The yield component most closely associated with the superior grain yield by Tcms hybrids was barrenness. Male-sterility reduced barrenness, depending on the year and location, 3 to 4% at the normal stand density and 7 to 12% at the high stand density. Male-sterility appeared to reduce the barrenness for the population intolerant genotype, 071 x 705, more than for population tolerant genotypes such as B14 x 577 and PX610; however, there were also substantial reductions in plant barrenness by some tolerant genotypes as exemplified by A619 x A632 and XL-45. Second ear development by some hybrids was noted in 1968 at 18,000 plants per acre with Tcms hybrids usually having the greater number of second ears. These results are in agreement with the work of Schwanke (1965) and Bruce et al. (1966) but disagrees with Josephson and Kincer (1962) who found no differences in the number of ears per plant.

The yield advantage of male-sterility was highly dependent upon the percentage of plants bearing ears as was exemplified by the late date of planting experiment. With almost no barrenness and second ear production precluded by the late planting date, grain yield at 18,000 plants per acre was decreased 4.1 bushels per acre with the T as compared to the N cytoplasm due to the general reduction in seed size noted with T cytoplasm. On the other hand, at 36,000 plants per acre where differences in barrenness due to sterility were expressed, the Tcms hybrids generally outyield their fertile counterparts. Comparisons of the barrenness of this late planting date with an early planting date (April 30) at another location showed less barrenness at 18 and 36,000 plants per acre with the late planting date. Environmental conditions were considered excellent for both locations. The lower barrenness for the late date of planting is in direct contrast to the results of Cardwell (1967) who found barrenness and nubbin ear production to increase with later dates of planting. These conflicting results point out that barrenness is an individual plant response to a given set of environmental conditions and that our knowledge of the physiological factors affecting or controlling barrenness is somewhat limited.

The effect of male-sterility on the weight of the ear was inconsistent across environments. In some instances, the superior yield of Tcms hybrids was attributed to a greater ear weight; however, generally the ear weight was not affected by male-sterility.

Kernel weight was significantly less in T than N cytoplasm ranging from nil to 0.7 grams per 100 seed for the various experiments. Since ear weight was generally similar for the two cytoplasms, the T cytoplasm must have increased the number of kernels per ear. Evidence for an increased number of kernels per ear was presented by Daynard (1968) for the fertile and detasseled male-sterile of UH 108 in which he found the kernels per row to be 28.7 and 30.9 respectively. The magnitude of the kernel weight response to male-sterility herein reported, however, was determined by the hybrid and environment in which the comparison was made.

Associated with the noted decreased barrenness with sterile cytoplasm was an earlier silking date. The 75% silking date was an average 1.2 to 3.7 days earlier with the T as compared to N cytoplasms; however, this response was dependent on the population level and hybrid. Tcms hybrids required 0.5 to 1.1 days and 2.0 to 3.4 days less to obtain 75% of the plants silking at 18 and 36,000 plants per acre respectively. Increasing the population from 18 to 36,000 plants per acre increased the silking date by 2.2 to 5.7 days for the normal hybrids whereas the silking date for Tcms hybrids was increased 0.7 to 2.7 days. This distinct advantage for the sterile cytoplasm in the 75% silking date probably accounted for the fewer barren plants noted for the Tcms hybrids. The association between delayed silking and barrenness was previously noted as an effect of increased plant population by Moss and Stinson (1961), Wooiley et al. (1962), Sass and Loeffel (1959), Schwanke (1965), and Cardwell (1967). Likewise, Schwanke (1965) reported an earlier silking date with male-sterile genotypes at 32,000 plants per acre. Other researchers (Jones, 1950; Noble and Russell, 1963; Marquez-Sanchez, 1964; Vincent, 1968) have noted a slightly earlier silking date at normal populations for sterile versions. The results obtained herein would indicate a similar effect; however, the cytoplasm by population interaction noted above has not been generally reported but was suggested by Marquez-Sanchez (1964) as a possible advantage for male-steriles at high plant populations.

The silking rate, days between 25 and 75% silking, can be looked on as representing a relative pollen-silking interval at a given population for comparison between the fertile and sterile counterparts. The silking rate ranged from 0.4 to 2.6 days faster with the T cytoplasm than the N cytoplasm. The silking rate was reduced by male-sterility by 0.0 to 0.3 days at normal stand density whereas the silking rate was 0.7 to 2.6 days faster at the high stand density with T than with the N cytoplasm. Increasing the population from normal to high increased the silking rate from 1.1 to 4.1 and 0.5 to 1.7 days for the N and T cytoplasms respectively. This was reflected in the earlier 75% silking date noted above. Woolley et al. (1962), Sass and Loeffel (1959), Moss and Stinson (1961), Dungan et al. (1958), and Cardwell (1967) have shown an increase in the pollen-silking interval with increasing stand densities. Kohnke and Miles (1951) and Lang et al. (1956) reported an average one-day delay in silking with a population increase of 3,500 to 4,000 kernels per acre. According to this, increasing the population from 18 to 36,000 plants per acre should have delayed the silking date by 4.5 to 5 days. Delays of this magnitude were noted for given normal hybrids, but Tcms hybrids decreased the pollen-silking interval substantially and seldom were delays greater than 3 days obtained with the T cytoplasm.

Hybrids differed markedly in their response to sterile cytoplasm with regard to the silking rate. In general the intolerant genotype had a slower silking rate, especially at the high population level, than tolerant genotypes. The variety 071 x 705's silking rate was 6.8 days faster with the sterile cytoplasm whereas the varieties B14 x 577 and PX610 had silking rates only 1.1 and 0.1 days faster respectively with T as compared to N cytoplasm at the high population in 1969. Those hybrids which had a slow silking rate tended to be those hybrids highest in barrenness (indicated by the significant correlation coefficient, r = 0.62) and usually gave the largest response to cytoplasmic male-sterility.

Leaf area index was found to be decreased by male-sterility by 0.26 and 0.18 in 1968 and 1969 respectively. The effect of sterility on leaf area did not vary appreciably with population, but the difference in leaf area tended to increase with higher populations indicating a constant cytoplasmic effect on leaf area at all populations. A similar decrease in the LAI by male-steriles was reported by Bruce et al. (1966) for the hybrid F44 x F6. Duvick (1965) noted that male-steriles had 1 to 2% less leaves than the male-fertiles for both the restored and nonrestored hybrids indicating that the leaf area between the restored and nonrestored male-steriles might be similar. Assuming this to be true, it is interesting to note the association between the 2 to 4% yield decrease with restored male-steriles reported by Duvick (1965), Noble and Russell (1963), and Marquez-Sanchez (1964) and the 2.5 to 3.7% decreased leaf area with the sterile cytoplasm at normal population noted herein. The decreased leaf area by Tcms hybrids might partially account for the decreased yield noted.

Grain per unit leaf area is a measure of the plant's efficiency of grain production. Male-sterility increased this efficiency slightly (0.18 grams/dm^2 in 1969 and 0.23 grams/dm^2 in 1968). This higher efficiency per unit leaf area for the sterile versions was the same at the 18 and 36,000 plants per acre even though the leaf area was increased approximately 80%

and was, in fact, mainly a reflection of the degree of barrenness observed for the two cytoplasms. This is shown in the correlation coefficient ($r = -0.74$) for barrenness and yield per unit leaf area. The higher efficiency per unit leaf area might be considered as a measure of the effect of pollen-sterility per se.

Cytoplasmic male-sterility has been shown to influence plant height most consistently of all factors reportedly affected by sterile cytoplasm. Average plant height for 15 hybrids was decreased 9.2 inches by the Texas cytoplasm. The hybrid had a slight effect on the response to the type of cytoplasm, but all 15 Tcms hybrids were shorter than their normal counterparts. These results are in complete agreement with many researchers. Grogan and Sarvella (1964) and Sarvella and Grogan (1965) have suggested that the nonsequential shortening of the internodes in the sterile as compared to their fertile counterparts may have risen from a temporary block or stimulation of the plant hormones regulating cell elongation or cell division.

One could hypothesize that the faster silking rate, less barrenness, and higher grain yields of the Tcms hybrids noted at high plant densities in this study, was possibly the result of a more optimum level of growth promoting substances during the critical period two weeks before anthesis. Lateral buds (ears in this case) are known to have lower optimum indoleacetic acid concentration than stems and leaves (Thimann, 1937). Possibly a more rapid ear development, as indicated by a slightly earlier silking date and rate for Tcms hybrids at the high population, was the result of lower amounts of growth promoting substances or possibly a more advantageous balance of these substances and thereby a less dominant tassel.

Schwanke[1], in some unpublished data using a bean internode elongation assay, found a composite of population tolerant fertile tassels at pre-emergence to have a lower concentration of growth promoting substances in the tassel than population intolerant tassels (relatively about 1/3 to 1/2 less); moreover, male-sterile tassels at pre-emergence had about 1/2 the growth promoting substances of the fertile tassels with intolerant male-sterile tassels only slightly less than tolerant fertile tassels. It is unclear how this hypothesis would explain ear growth at normal populations unless the ear was "pushed out" by an abundance of stalk sugar and reduced nitrogen against the inhibition by the tassel. This area of hormonal control by the tassel on ear development needs further research and should prove fruitful in eliciting the physiological determinates of barrenness and population tolerance.

Male-sterility had little appreciable influence on the harvest moisture or shelling percentage. The harvest moisture was slightly higher (less than 1%) in fertile as compared to sterile counterparts. The lower harvest moisture is a reflection of the earlier 75% silking date which would cause slightly earlier maturity. However, as Marquez-Sanchez (1964) concluded, the effect of cytoplasm on grain moisture was small and of no practical importance.

Plant lodging was quite high in this investigation due to the high populations utilized and severe damaging winds sustained. Under these extreme stress conditions, Tcms hybrids were found to have inferior stalk

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[1] Schwanke, R., Arlington, Virginia. Relative growth promoting substances of tassels. Private communication. 1965.

qualities as indicated by the 11.6% greater lodging by the sterile versions in addition to the 38.7% lodging by fertile counterparts in 1969. The higher plant lodging would hinder the use of male-sterility. These results are in contrast to Josephson and Kincer (1962), Rogers and Edwardson (1952), and Neal and Strommen (1956) who reported no consistent effect of male-sterility on agronomically important characteristics such as stalk and root lodging but did agree with Johnston and Snyder (1962).

Population by Row Spacing Study

The major objective of this series of experiments was to study the population by row spacing interaction and to further verify the male-sterile response at high plant densities. Several investigations have shown that the use of narrow rows resulted in a higher efficiency of light interception (Denmead et al., 1962; Yao and Shaw, 1964b), water utilization (Yao and Shaw, 1964a), and higher grain yields (Colville and Burnside, 1963; Stickler, 1964; Woolley et al., 1962; Thompson, 1967). Observations of 20-inch rows during 1967 at very high plant populations revealed that only the uppermost leaves were exposed to appreciable light flux. Tanner and Daynard (1967) have indicated the importance of proximity of the leaf to the ear as a factor in determining the actual and potential contribution of a leaf to grain yield. Therefore, it was postulated that possibly reduced light and/or gaseous exchange to the ear leaf at very high populations and narrow rows might prove more detrimental to grain yield than interplant competition within a wider row.

This hypothesis was, however, not substantiated by these experiments. Little differences in grain yield were noted between the 10-, 30-, and 40-

inch row spacings at 45,000 plants per acre while 20-inch rows were more than 5 bushels per acre less than the other row spacings in Experiment 6. Grain yield was 2.0 bushels per acre higher in 40-inch rows than 20-inch rows for 10 hybrids at 54,000 plants per acre in Experiment 7. Yields at normal populations were very similar across these row spacings.

One of the arguments for the narrow row advantage, when reported, is that interplant competition is reduced. If one could assume this to be true for very high plant densities also, one would expect the wider row spacing to have had a lower relative yield than narrower rows. This, however, was not the case in these experiments.

Further evidence that wide rows might have an advantage over narrow rows at very high populations was noted in Experiment 7 in which an average 2.9 days earlier 75% silking date was found for the 40-inch rows at the high plant density whereas 0.7 days delay was noted at the low population in 40-inch rows. This led to a highly significant row spacing by population interaction. The observed earliness might be partially explained by the greater percent light intercepted above the ear leaf noted for narrow rows (92.7% and 80.3% for 10- and 40-inch rows respectively). Light measurements were taken within two hours of solar noon; therefore, light penetration was close to maximum. A greater light flux density penetrated deeper into the canopy for a longer period each day, possibly accounting for the earlier 75% silking date noted. However, this earliness was not noted in Experiment 6. The reason for this interaction between high plant densities and row spacing on silking is not fully understood.

Grain yield, barrenness, 75% silking date, silking rate, and kernel weight as influenced by the population, cytoplasm, and hybrid were very similar to those discussed in the previous section. The cytoplasm type interacted with population for grain yield in almost identical fashion in Experiment 6 as the two 1969 experiments (4 and 5), but absolute yield levels were considerably lower. Furthermore, Experiments 2 and 8, which were conducted at the same site, gave similar responses with respect to the grain yield patterns. Further discussion for these experiments would be repetitious; however, Experiment 8 was somewhat contradictory of previous results.

Male-sterility did not significantly affect grain yield at any of the stand densities used in Experiment 8. This was somewhat misleading since the hybrids individually had an affect on grain yield. Variety SX 29 followed the previously mentioned pattern for Tcms hybrids at the various stand levels, but the variety P3306 yielded significantly more with the N than with the T cytoplasm at all population levels. This is somewhat puzzling in that the same genotype had a highly significant grain yield in favor of the T cytoplasm the previous year. The 75% silking date and silking rate exhibited the normal response to sterility with barrenness differences deviating slightly. Recently, most Tcms hybrids (restored and non-restored) have been noted to be susceptible to a leaf blight organism, Phyllosticta Zeae (Scheifelo et al. 1969). If serious infections occur, sizable yield reductions are noted. Phyllosticta Zeae infections could have been responsible for the grain yield pattern noted for P3306, but one might have expected to observe the same yield response from SX 29. These results are not fully understood.

Results of this investigation are in agreement with the earlier work of Duvick (1958), Grogan (1956), Chinwuba et al. (1961), Sanford et al.

(1965), and Schwanke (1965). As these authors suggested, male-sterility decreased the competition between the ear primordia and the tassel for available photosynthates or nutrients. At the high plant populations, the importance of this competition became very evident. The availability of a larger amount of photosynthates and/or possibly more reduced nitrogen for ear and silk elongation probably explained the more rapid silk elongation and earlier silking date noted for Tcms hybrids. This was mainly reflected in the lower barrenness observed for male-steriles. It must be concluded, as other workers have found, that the period from anthesis to 2 plus weeks before anthesis is critical in the development of the ear. However, the physiological determinates of plant barrenness and the male-sterile response might be more basic than the competition for nutrients and photosynthates as suggested in the argument for hormonal regulation in the "release" of the ear.

As farmers push corn plant populations ever higher, plant barrenness becomes the major limiting factor in increased production. Data presented here indicates that male-sterility reduces the adverse effects of high populations, i.e. plant barrenness. Through the use of seed blends and the heterozygous allele for pollen restoration, the stability at normal stand densities and the increased population tolerance at high plant densities for Tcms single-cross hybrids can and should be utilized by the agricultural industry.

SUMMARY

The effect of cytoplasmic male-sterility at high plant densities for several single-cross hybrids was investigated in a series of experiments during 1967 thru 1969. Plant characteristics measured in all experiments were grain yield, barrenness, silking date, and silking rate. Ear weight, kernel weight, leaf area, yield per unit leaf area, plant height, harvest moisture, and shelling percentage were measured in some experiments.

Results of this investigation indicate that male-sterile cytoplasm affected agronomic characteristics of single-cross hybrids in addition to preventing pollen production. However, the magnitude of the male-sterile response was determined by the hybrid, population, and environment in which the comparisons were made.

Cytoplasmic male-sterility increased mean grain yield from 0.05 to 13.8% with an average of about 7%. Population intolerant genotypes as exemplified by 071 x 705 tended to respond greater to male-sterility than population tolerant genotypes like B14 x 577. However, population tolerant genotypes such as A619 x A632 and XL-45 did produce significantly higher yields with T than N cytoplasm. At normal plant densities (15 to 18,000 plants per acre) Tcms hybrids yielded similar to their fertile counterparts unless an environmental stress gave a relative advantage to the sterile. On the other hand, grain yields at high plant densities (30 to 36,000 plants per acre) were significantly different with Tcms hybrids tending to increase grain yield slightly over that of the normal population while normal hybrids decreased their grain yield substantially. Therefore, the hybrids' tolerance to population stresses was enhanced by incorporation of

the sterile cytoplasm. Generally male-sterility maintained its advantage at extremely high plant populations (45 to 54,000 plants per acre), but this response was variable. Yield at the optimum population between N and T cytoplasms was not significantly different.

Plant barrenness was cytoplasmically influenced in all experiments. Male-sterility decreased the mean barrenness by approximately 4 to 8%, accounting for a major part of the increased yield noted above. At normal populations, little differences in barrenness were noted between the N and T cytoplasms with some tendency for more double ears noted with T cytoplasm. At high plant densities, male-sterility decreased plant barrenness substantially (4 to 20%).

Barrenness was related to the date and rate of silking. Tcms hybrids required fewer days to obtain the 75% silking date (mean 1.5 to 3.7 days depending on the experiment). At normal populations, the 75% silking date was decreased 0.1 to 1.1 days whereas at the high population this date was decreased 2.0 to 3.4 days with the T than with the N cytoplasm. The silking rate was significantly faster with T than N cytoplasm. At the normal stand densities, Tcms hybrids silked 0.0 to 0.3 days faster whereas at the high stand densities Tcms hybrids silked 0.7 to 1.9 days faster. At extremely high stand densities, the effect of T cytoplasm on the silking date and rate was even more contrasting. Earliness associated with male-sterility was the result of a slightly earlier silk emergence and a considerably faster silking rate. Both the silking rate and date response to sterility were markedly influenced by the hybrid.

Ear weight response to sterility varied with the experiment with small decreases or increases depending on the particular hybrid. Higher yields by Tcms hybrids not fully explained by barrenness were explained by the ear weight, but no consistent effect of cytoplasm type was noted on ear weight.

Kernel weight was consistently reduced with the T cytoplasm by a mean 0.3 to 0.6 grams per 100 seed. Hybrids interacted significantly with the cytoplasm with respect to kernel weight. Population level had little influence on the response of kernel weight to sterility.

Leaf area index was decreased with T as compared to N cytoplasm (2.8 to 3.7% depending on the experiment). This difference might account for the decreased yield associated with the restorer mechanism when in sterile cytoplasm. Leaf efficiency was higher with Tcms than with normal hybrids. This increased efficiency might be a measure of the effect pollen-sterility *per se* has, and it reflects the decreased barrenness noted with sterile cytoplasm.

Plant height was decreased by male-sterility for all hybrids measured. Mean plant height was decreased 8.8%, but the absolute decrease depended on the variety. Plant lodging was higher for Tcms than normal hybrids at the high populations indicating a slightly inferior stalk quality.

Changes in grain moisture at harvest caused by male-sterility were significant but would be considered of little practical importance. Shelling percentage was not a significant source of variation between the types of cytoplasm.

Rows spaced 40 inches apart were found to yield similarly to 20-inch rows at very high plant densities (45 to 54,000 plants per acre); however, a slightly earlier silking date and faster silking rate were found in one experiment which might reflect the greater light flux density reaching the ear leaf.

The response to cytoplasmic male-sterility might be associated with a reduced competition between the ear primordia and the dominant tassel for available photosynthates and/or nutrients as previously suggested; however, it was concluded from the variability among hybrids and within a hybrid among environments that the effect of cytoplasmic male-sterility on a plant's performance is unclear and might be under hormonal control.

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APPENDIX

Table 57. Plant characteristics and response of 15 fertile hybrids and their male-sterile counterparts to 2 population levels in 1967

Hybrid	Cyto-plasm	Plants/ acre 1000's	Combine yield (bu/a)	% barren	Mid-silking date	Silking rate (days)	Wt/100 seed (grams)	Plant height (inches)
071 x 705	F	19.8	98.8	2.5	8-5.8	2.8	24.0	107.5
		32.0	82.8	29.0	8-9.8	11.3	21.5	107.8
	S	15.8	110.8	2.5	8-2.3	3.8	25.4	102.5
		30.8	107.3	17.3	8-3.8	4.0	23.6	98.0
P3510	F	23.5	109.3	19.8	8-1.0	6.3	23.0	109.8
		33.5	107.3	47.0	8-4.3	9.8	22.0	112.3
	S	24.0	108.3	5.0	7-30.5	4.3	22.7	95.5
		43.3	109.0	14.5	8-1.0	4.0	20.8	94.5
B14 x 577	F	20.5	121.5	11.3	7-30.8	2.8	27.0	105.5
		39.0	121.0	21.8	8-2.5	5.5	21.4	108.5
	S	18.0	123.0	0.0	7-30.3	3.8	26.8	100.5
		43.0	132.5	10.5	8-1.5	3.0	23.5	98.8
M2036	F	19.0	103.8	12.5	8-3.0	3.3	23.9	104.3
		41.3	105.5	36.8	8-6.0	5.5	20.8	111.0
	S	20.8	126.8	10.3	8-0.5	2.5	25.2	97.3
		38.8	118.0	15.8	8-3.0	3.3	23.0	96.3
336 x 025	F	19.5	95.5	4.5	7-28.8	1.3	23.8	101.3
		40.8	102.3	25.3	7-30.5	2.0	23.4	102.3
	S	20.0	81.8	1.8	7-28.8	2.8	22.2	92.8
		37.5	87.0	10.5	7-28.3	3.5	21.0	90.8
425 x 091	F	19.5	109.0	10.0	7-29.0	2.0	24.1	106.8
		41.8	131.5	32.3	7-31.0	4.5	23.9	104.3
	S	18.5	122.5	2.0	7-28.3	2.3	23.9	97.5
		35.3	121.5	19.3	7-30.5	2.0	21.6	96.8
544 x 216	F	17.8	115.0	4.0	8-1.8	3.3	26.0	109.0
		31.0	124.5	18.5	8-2.3	4.0	23.5	107.3
	S	16.3	94.3	0.8	8-1.5	4.3	23.9	97.8
		34.5	132.3	8.5	8-0.5	4.5	23.4	98.8
336 x 029	F	20.0	123.0	5.5	7-28.5	1.5	25.0	108.0
		34.5	118.3	12.3	7-28.3	2.0	21.8	111.0
	S	16.8	130.8	1.3	7-26.3	2.0	27.0	103.3
		32.5	121.3	3.5	7-28.0	2.0	20.2	99.8

Table 57. (Continued)

Hybrid	Cyto-plasm	Plants/ acre 1000's	Combine yield (bu/a)	% barren	Mid-silking date	Silking rate (days)	Wt/100 seed (grams)	Plant height (inches)
155 x 526	F	18.5	113.5	9.3	8-2.0	2.3	24.0	98.8
		36.3	115.3	27.8	8-5.5	3.0	23.7	103.0
	S	17.5	119.5	4.8	8-0.3	2.0	27.4	90.0
		34.5	109.0	26.3	8-1.3	4.3	25.4	88.0
UH 138	F	19.0	112.5	7.8	7-27.0	2.5	22.8	95.0
		40.8	121.5	24.5	7-31.0	2.8	20.2	89.8
	S	23.3	115.5	3.8	7-29.0	2.8	23.6	82.3
		38.3	141.8	4.8	7-27.8	2.3	21.4	85.8
UH 108	F	21.0	89.5	1.3	7-25.0	0.5	22.5	85.3
		44.5	89.0	20.5	7-25.3	0.3	21.9	82.5
	S	22.0	65.8	11.5	7-25.0	0.5	20.7	74.8
		39.3	90.8	15.3	7-25.3	0.8	20.5	71.3
SX 63	F	24.3	109.5	13.3	8-1.3	2.3	23.5	114.0
		34.5	102.5	35.0	8-5.0	5.3	20.5	117.0
	S	19.0	120.3	6.5	8-1.3	2.0	23.2	107.3
		33.8	124.0	10.0	8-1.8	4.8	19.4	106.5
SX 9	F	17.3	113.8	4.5	7-26.5	1.8	27.9	100.8
		32.5	110.3	7.5	7-29.3	2.8	24.8	98.8
	S	16.5	114.3	6.5	7-29.5	3.8	25.0	86.5
		24.8	119.3	4.5	7-29.0	2.0	24.5	89.5
SX 29	F	17.5	125.3	0.0	8-0.8	3.3	25.2	110.8
		30.0	133.0	17.3	8-3.5	3.3	21.8	112.5
	S	19.3	138.0	2.5	8-0.8	2.3	26.6	107.0
		36.0	127.5	10.5	8-3.3	3.0	20.9	104.5
PX610	F	20.5	119.5	8.8	7-30.5	2.8	26.0	104.8
		39.3	131.5	17.0	8-0.8	3.0	22.8	109.3
	S	20.3	124.0	6.5	7-29.3	3.8	26.7	104.3
		34.8	135.8	16.5	8-0.5	5.3	23.7	105.5

Table 58. Plant characteristics and the mean squares for the response of 15 fertile hybrids and their male-sterile counterparts at 2 population levels in 1967

Source	d.f.	Yield	% barren	Mid-silk date	Silking rate	Kernel weight	Plant height
Blocks	3	3222**	242.2	97.1**	8.9	29.8**	1122.8**
Hybrids (H)	14	2802**	362.5**	137.1**	29.1**	26.6**	1138.8**
Error (a)	42	259	95.7	11.3	4.9	3.8	49.3
Cytoplasm (C)	1	909*	3650.4**	100.1**	11.3	0.0	5032.5**
H x C	14	377**	179.9*	8.6	9.7	8.1**	39.3*
Error (b)	45	153	73.2	4.3	5.5	1.9	16.4
Population (P)	1	932**	9601.3**	168.3**	74.8**	344.6**	0.1
H x P	14	368**	131.2*	3.8	6.1	8.1**	11.0
C x P	1	134	1224.0**	27.3**	25.3*	0.4	61.0
H x C x P	14	232	54.3	3.5	6.1	3.1	21.6
Error (c)	90	135	62.1	3.8	4.9	1.9	18.3
Coefficient of variation (%)		10.2	63.9	6.3	69.5	6.0	4.2

*Statistical significance at the 5% level of probability.

**Statistical significance at the 1% level of probability.

Table 59. Plant characteristics and response of 10 fertile hybrids and their male-sterile counterparts to 4 population levels in 1968

Hybrid	Cytoplasm	Pop[1]	Harvest plants /plot	Grain yield (bu/a)	Combine yield (bu/a)	Ears/ 100 stalks	75% silking date	Silking rate (days)	Wt/100 seed (grams)	Percent lodging	LAI
A619 x A632	F	1	14.5	140	144	102	7-17.6	1.6	29.3	7.5	3.05
		2	27.5	129	133	78	7-23.9	8.0	28.2	13.8	5.70
		3	33.8	122	120	69	8-1.5	14.3	27.7	41.3	8.85
		4	39.0	124	113	60	7-31.0	13.5	27.9	33.8	10.50
	S	1	15.5	159	156	103	7-17.6	1.4	27.9	5.0	3.15
		2	26.5	151	153	93	7-18.8	2.3	27.0	22.5	5.65
		3	34.3	137	146	74	7-23.5	6.8	28.0	36.3	8.00
		4	43.8	135	139	70	7-25.8	8.8	28.4	30.0	9.50
UH 138	F	1	16.3	132	132	92	7-19.8	2.6	25.3	0.0	3.55
		2	27.3	124	126	76	7-27.9	7.1	23.8	0.0	6.75
		3	36.3	116	103	68	8-3.4	11.3	23.2	3.8	8.25
		4	42.0	76	97	38	8-0.8	11.1	23.6	15.0	11.70
	S	1	14.8	145	150	95	7-18.8	1.8	24.1	0.0	3.50
		2	28.0	143	143	88	7-22.3	4.3	23.2	0.0	6.60
		3	33.0	133	125	76	7-26.1	6.3	23.8	10.0	8.75
		4	38.3	120	130	66	7-26.0	5.4	24.3	11.3	11.45
P3510	F	1	15.8	123	139	76	7-23.9	2.5	28.3	22.5	3.30
		2	27.8	80	74	47	8-8.8	14.5	27.2	25.0	6.55
		3	32.8	83	74	46	8-6.9	12.5	27.7	25.0	9.55
		4	38.3	68	79	38	8-16.0	21.0	26.9	31.3	11.15
	S	1	15.5	170	157	100	7-22.4	2.6	27.0	38.8	3.40
		2	28.5	133	128	77	8-0.6	9.9	27.6	41.3	6.45
		3	34.0	124	103	64	8-6.3	13.8	27.0	33.8	8.20
		4	42.0	101	100	48	8-8.3	16.9	27.6	31.3	10.45
336 x 025	F	1	16.0	110	101	94	7-19.0	1.9	23.4	21.3	2.95
		2	26.8	109	83	83	7-20.4	2.8	20.1	35.0	5.30

[1]Population level in plants/acre: 1 = 18,000, 2 = 36,000, 3 = 54,000, 4 = 72,000.

Table 59. (Continued)

Hybrid	Cyto-plasm	Pop[1]	Harvest plants /plot	Grain yield (bu/a)	Combine yield (bu/a)	Ears/ 100 stalks	75% silking date	Silking rate (days)	Wt/100 seed (grams)	Percent lodging	LAI
		3	35.5	96	83	70	7-22.3	4.3	20.2	47.5	6.55
		4	42.8	77	78	53	7-26.8	7.4	21.0	55.0	9.80
	S	1	15.3	114	103	102	7-19.1	2.0	22.0	12.5	2.60
		2	27.5	109	101	91	7-20.0	2.3	19.7	41.3	5.35
		3	33.3	99	94	72	7-21.4	3.1	20.2	33.8	7.25
		4	44.0	97	85	69	7-23.4	5.3	18.8	62.5	9.10
P3306	F	1	15.5	164	157	99	7-23.4	1.6	32.7	6.3	3.60
		2	25.8	140	146	82	7-30.1	6.6	30.7	12.5	6.85
		3	33.0	120	121	66	8-2.1	7.9	30.2	26.3	9.40
		4	40.5	120	101	55	8-9.0	14.9	30.9	33.8	11.70
	S	1	14.5	168	172	99	7-23.8	2.3	32.0	10.0	3.55
		2	23.5	157	173	86	7-27.3	5.1	32.0	17.5	6.65
		3	37.3	139	147	71	7-29.4	6.3	31.7	27.5	9.40
		4	42.3	130	120	62	7-4.5	10.3	30.8	26.3	11.80
B14 x 577	F	1	15.3	142	143	109	7-23.8	2.6	29.8	0.0	3.90
		2	25.0	142	139	86	7-24.8	3.0	27.1	0.0	7.65
		3	38.8	122	134	59	8-4.3	13.0	27.5	3.8	8.80
		4	43.5	133	128	63	8-5.4	13.0	26.5	0.0	12.35
	S	1	16.2	148	148	113	7-22.5	1.9	29.3	0.0	3.55
		2	23.8	138	142	91	7-23.9	2.6	27.1	1.3	6.85
		3	36.0	126	133	75	7-29.8	7.3	25.8	7.5	10.70
		4	40.8	126	132	57	7-29.8	6.9	25.6	2.5	11.40
336 x 029	F	1	15.8	125	120	99	7-18.5	1.9	24.7	10.0	2.75
		2	28.5	118	112	80	7-20.0	3.1	20.1	32.5	4.80
		3	34.5	119	102	76	7-27.6	9.9	20.4	42.5	7.75
		4	41.5	105	87	67	7-24.0	6.1	19.4	60.0	9.50
	S	1	14.8	138	133	120	7-18.5	1.9	24.7	8.8	2.70
		2	30.0	128	114	86	2-19.3	2.3	18.9	33.8	4.60

Table 59. (Continued)

Hybrid	Cyto-plasm	Pop[1]	Harvest plants /plot	Grain yield (bu/a)	Combine yield (bu/a)	Ears/ 100 stalks	75% silking date	Silking rate (days)	Wt/100 seed (grams)	Percent lodging	LAI
		3	34.8	109	109	76	7-21.0	4.0	18.7	47.5	6.65
		4	39.0	101	97	65	7-24.5	7.0	18.6	61.3	7.70
SX 29	F	1	15.3	121	121	97	7-24.5	2.0	27.9	36.3	3.55
		2	26.8	86	85	70	7-31.0	6.4	24.9	36.3	6.30
		3	28.8	63	77	56	8-5.1	10.6	24.3	32.5	9.60
		4	32.8	67	71	48	7-4.0	7.6	24.4	36.3	10.65
	S	1	15.5	136	138	96	7-23.6	1.4	27.5	21.3	3.54
		2	30.0	124	117	84	7-26.5	3.1	24.3	42.5	6.35
		3	34.5	117	98	73	7-28.8	4.3	25.6	58.8	8.35
		4	38.0	72	81	55	8-0.4	6.6	24.0	48.8	10.55
PX610	F	1	14.0	134	126	98	7-20.8	3.1	28.3	32.5	3.50
		2	27.8	141	114	84	7-25.0	5.6	27.6	47.5	6.30
		3	31.5	115	106	70	7-26.1	5.6	27.1	60.0	8.85
		4	37.0	105	104	59	8-9.0	19.0	26.5	66.3	10.80
	S	1	16.8	166	147	97	7-19.5	2.3	28.8	30.0	3.50
		2	25.0	142	131	85	7-22.8	2.9	27.6	57.5	6.05
		3	36.0	141	126	79	7-24.5	4.5	28.2	55.0	8.50
		4	38.3	101	110	59	7-26.5	5.1	27.2	65.0	11.15
XL-45	F	1	15.3	139	144	103	7-18.0	1.9	27.7	0.0	3.01
		2	25.0	125	128	87	7-23.4	6.1	25.2	10.0	6.00
		3	39.8	119	116	61	8-2.3	13.6	26.0	5.0	8.50
		4	45.8	113	110	59	7-26.3	8.0	25.2	3.8	11.00
	S	1	15.5	154	156	111	7-19.8	3.0	26.3	5.0	2.95
		2	25.0	139	150	96	7-19.5	2.5	23.0	3.8	5.65
		3	40.5	136	130	77	7-23.8	6.0	24.3	15.0	8.35
		4	42.3	118	131	60	7-22.9	5.1	23.3	2.5	10.65

Table 60. Plant characteristics and mean squares for the response of 10 fertile hybrids and their male-sterile counterparts to 4 population levels in 1968

Source	d.f.	Combine yield	Grain yield	Ears/100 stalks	Ear weight	Kernel weight
Blocks	3	2285**	2219**	279	878**	7.5**
Hybrids (H)	9	10121**	7287**	1316**	7959**	359.2**
Error (a)	27	193	295	112	179	2.4
Population (P)	3	18322**	19453**	27205**	165829**	91.4**
Cytoplasm (C)	1	22375**	19587**	5771**	323	14.5**
P x C	3	225	213	58	504*	1.5
H x P	27	563**	466*	112	734**	5.2**
H x C	9	523**	1319**	217**	212	4.2**
H x P x C	27	118	288	121*	200	1.4
Error (b)	210	140	268	72	196	1.1
Coefficient of variation (%)		9.9	13.4	11.0	10.7	4.0

*Statistical significance at the 5% level.

**Statistical significance at the 1% level.

Table 60. (Continued)

Source	d.f.	Harvest population	75% silking	Silking rate	Percent lodging	d.f.	LAI
Blocks	3	43.2*	64.6*	25.3	1292*	1	0.20
Hybrids (H)	9	29.5	581.8**	149.2**	9293**	9	8.61**
Error (a)	27	14.0	21.8	20.7	428	9	0.19
Population (P)	3	9554.8**	1726.3**	968.1**	6549**	3	400.94**
Cytoplasm (C)	1	11.3	1042.2**	634.2**	383	1	2.58**
P x C	3	3.7	109.4**	76.2**	129	3	0.39
H x P	27	30.0**	45.5**	33.8**	521**	27	0.55*
H x C	9	21.6	14.8	13.3	115	9	0.28
H x C x P	27	10.6	16.4	15.1	133	27	0.42
Error (b)	210	12.4	14.2	13.5	172	70	0.26
Coefficient of variation (%)		11.9	14.2	58.0	51.8		7.0

Table 61. Plant characteristics and the mean response of 5 fertile hybrids and their male-sterile counterparts to 2 population levels in 1969

Hybrid	Cyto-plasm	Plants desired /plot	Harvest plants /plot	Grain yield (bu/a)	% barren	Ear wt. grams/ ear	Wt/100 seed (grams)	LAI
UH 108	F	21	20.3	96.1	6.2	131	26.3	1.91
		41	40.3	116.6	19.9	94	22.8	3.54
	S	21	19.5	94.1	5.1	131	24.6	1.78
		41	40.5	134.9	11.1	98	23.6	3.57
155 x 526	F	21	20.8	156.6	2.4	221	30.0	3.19
		41	36.8	126.1	25.8	115	28.1	5.82
	S	21	21.5	149.3	2.3	216	28.2	3.12
		41	39.8	126.6	20.7	112	28.0	5.23
425 x 091	F	21	21.5	172.6	4.7	228	28.2	2.95
		41	40.8	139.4	27.7	144	26.0	5.15
	S	21	21.0	162.7	6.0	234	27.1	2.61
		41	40.8	159.1	9.2	116	22.8	4.49
544 x 216	F	21	20.5	161.8	3.7	235	31.4	3.44
		41	38.0	159.5	17.0	138	28.8	6.21
	S	21	20.3	168.3	0.0	238	31.5	3.37
		41	40.0	171.5	11.8	133	26.9	5.95
071 x 705	F	21	21.0	153.1	17.9	215	23.9	3.82
		41	40.0	100.6	51.3	116	21.5	6.52
	S	21	21.0	159.9	11.9	187	25.4	3.73
		41	40.3	138.2	21.2	98	23.6	5.99

Grain /L.A. gm/dm^2	Number of ears /plot	75% silking date	Silking rates (days)	Harvest moisture %	Shelling %	Lodging %	Combine yield (bu/a)
2.89	19.0	7-10.8	2.2	20.0	86.2	17.5	84.5
1.89	32.5	7-13.4	3.5	20.0	85.5	18.8	103.3
3.09	18.5	7-9.3	1.0	20.0	83.4	20.0	85.8
2.18	36.0	7-10.8	2.0	20.0	85.6	20.0	119.4
3.01	20.5	7-23.7	2.7	23.7	83.8	40.0	151.1
1.30	27.3	7-25.7	3.4	24.8	83.5	26.3	119.0
3.02	21.3	7-19.8	1.9	22.7	83.0	55.0	149.6
1.50	31.5	7-21.9	2.2	22.8	82.9	47.5	124.7
3.27	22.3	7-18.1	1.5	19.4	88.3	21.3	146.6
1.74	29.3	7-23.8	5.4	19.4	88.7	38.8	143.8
3.75	21.5	7-17.4	1.4	18.7	88.5	26.3	153.5
2.08	37.3	7-18.8	2.2	18.6	87.6	62.5	145.4
2.91	20.0	7-19.5	2.0	19.8	84.5	3.8	159.7
1.65	31.5	7-23.4	2.8	19.4	81.9	13.8	163.2
3.15	20.3	7-19.4	1.8	18.5	84.2	8.8	168.5
1.76	35.3	7-22.9	3.0	19.0	84.0	20.0	164.6
2.06	17.3	7-25.6	2.8	31.0	--	0.0	116.8
0.77	19.5	8-9.0	12.8	34.0	--	0.0	73.1
2.21	20.8	7-23.6	2.0	31.0	--	0.0	121.6
1.15	31.8	7-29.5	6.1	34.0	--	0.0	100.5

Table 62. Plant characteristics and the mean squares for the response of 10 hybrids at 2 populations in 1969

Source	d.f.	Grain yield	Combine grain yield	% barren	Ear weight	Kernel weight
Blocks	3	110	144	60	691	2.4
Hybrids (H)	9	5400**	8886**	316**	8161**	84.2**
Error (a)	27	151	130	31	300	2.3
Population (P)	1	616	124	6782**	349428**	258.6**
Cytoplasm (C)	1	3795**	787**	2078**	1970**	16.3**
P x C	1	2240**	123	402**	31	0.7
H x P	9	1723**	1365**	147**	1854**	5.1**
H x C	9	248	100	181**	383	5.7**
H x P x C	9	153	92	46	234	2.3
Error (b)	90	186	81	32	192	1.2
Coefficient of variation (%)		8.99	6.3	48.0	8.1	4.0

*Significant at the 5% level of probability.

**Significant at the 1% level of probability.

Table 62. (Continued)

Source	d.f.	Ears/ plot	50% silking date	75% silking date	Silking rate	Plants harvested
Blocks	3	9.0	3.5	9.4*	4.1	2.9
Hybrids (H)	9	59.8**	327.9**	405.5**	23.9**	4.7
Error (a)	27	5.3	1.3	3.0	2.1	2.9
Population (P)	1	4741.5**	180.1**	396.9**	120.8**	13745.5**
Cytoplasm (C)	1	283.6**	120.3**	204.8**	47.3**	5.2
P x C	1	142.5**	16.7**	46.8**	20.0**	3.3
H x P	9	32.2**	9.9**	26.9**	15.6**	5.6
H x C	9	22.8**	9.5**	12.7**	4.6*	3.1
H x P x C	9	8.0	4.7**	7.5**	4.6*	2.2
Error (b)	90	5.2	1.3	2.3	1.8	3.1
Coefficient of variation (%)		8.3	6.3	7.8	51.6	5.8

Table 62. (Continued)

Source	d.f.	LAI	Grain /L.A.	% moisture	% shelling	% lodging
Blocks	3	0.07	0.03	0.78	0.3	287
Hybrids (H)	9	7.62**	3.39**	350.32**	42.1**	4740**
Error (a)	27	0.08	0.07	1.19	1.8	127
Population (P)	1	220.59**	85.85**	0.06	1.7	10726**
Cytoplasm (C)	1	1.26**	1.28**	33.40**	1.0	5880**
P x C	1	0.19	0.00	0.06	3.7	1823**
H x P	9	0.42**	0.39**	5.38**	2.6	1098**
H x C	9	0.19**	0.09	2.01**	2.1	338**
H x P x C	9	0.05	0.03	0.50	1.5	187
Error (b)	90	0.07	0.05	0.46	1.8	150
Coefficient of variation (%)		6.5	9.1	3.3	1.6	40.3

Table 63. Plant characteristics and the response of 5 fertile hybrids and their male-sterile counterparts to 5 population levels in 1969

Hybrid	Cyto-plasm	Plants desired /plot	Har-vest plants /plot	Grain yield (bu/a)	Barren %	Ear wt. grams/ ear	Wt/ 100 seed grams	LAI	Grain /L.A. gm/ dm^2
PX610	F	21	20.8	160.6	3.6	208	30.4	2.96	3.41
		27	27.0	174.0	8.9	195	28.4	3.70	2.97
		34	33.0	168.9	12.0	163	27.1	4.75	2.25
		41	41.5	184.1	13.8	147	26.7	5.22	2.22
		62	58.0	156.2	34.3	117	25.1	7.16	1.39
	S	21	20.5	167.6	3.7	227	29.8	3.14	3.35
		27	27.0	179.7	7.3	190	28.1	3.88	2.91
		34	35.5	200.5	6.1	169	27.4	5.03	2.50
		41	39.3	182.7	10.1	146	26.3	5.39	2.13
		62	57.8	166.4	24.0	109	27.1	6.86	1.15
XL-45	F	21	21.8	150.4	9.0	196	29.5	2.32	4.08
		27	29.0	156.9	9.4	170	28.8	3.34	2.97
		34	34.0	152.6	19.0	152	28.1	4.40	2.18
		41	39.5	141.7	20.3	126	26.8	4.59	1.94
		62	56.5	117.7	43.7	104	26.1	6.71	1.11
	S	21	22.0	157.3	5.6	194	28.1	2.47	4.00
		27	26.8	174.0	0.9	185	26.9	3.20	3.36
		34	33.5	171.6	6.9	155	25.5	3.88	2.80
		41	41.3	168.2	15.7	138	24.9	4.78	2.20
		62	55.3	130.5	37.1	106	24.4	6.37	1.29
B14 x 577	F	21	21.0	159.9	8.5	190	30.3	3.35	2.99
		27	28.0	155.5	13.4	187	28.6	4.59	2.13
		34	34.0	153.5	14.7	157	26.7	5.44	1.77
		41	37.5	143.5	19.9	139	26.5	6.23	1.45
		62	52.0	130.8	36.3	118	25.3	7.86	1.06
	S	21	21.0	161.9	7.2	208	30.1	3.06	3.33
		27	27.0	169.3	4.6	184	28.5	4.05	2.63
		34	34.0	149.2	12.4	150	26.9	5.08	1.86
		41	39.0	151.1	16.4	138	25.9	5.96	1.59
		62	50.3	122.9	33.9	112	25.2	7.82	1.00

50% silk-ing (date)	Silking rate (days)	Harvest moisture %	% shelling	Lodging %	Combine yield (bu/a)	Number of ears /plot	Nubbins	75% silking (date)
7-16.3	2.2	19.2	87.6	26.3	150.3	21.8	0.00	7-17.4
7-16.4	2.0	18.5	88.1	41.3	163.7	25.0	0.00	7-17.7
7-17.2	2.9	18.5	86.7	70.0	153.5	29.5	1.50	7-19.0
7-17.8	2.6	18.9	86.6	50.0	166.0	35.8	0.00	7-19.3
7-20.3	3.8	18.1	86.7	71.3	138.1	38.0	1.25	7-22.4
7-15.8	1.5	19.0	87.6	15.0	157.3	20.8	0.50	7-16.8
7-16.3	1.5	18.8	87.2	33.8	160.8	26.8	0.50	7-17.8
7-16.8	1.6	18.4	87.1	57.5	173.6	33.5	0.25	7-17.9
7-17.9	2.5	17.9	87.4	80.0	170.0	35.3	0.00	7-19.2
7-19.9	3.7	18.9	86.9	66.3	149.5	44.0	1.00	7-21.7
7-14.8	1.3	20.6	86.1	10.0	146.5	22.0	1.00	7-15.4
7-15.3	1.8	19.3	85.9	11.3	162.5	26.5	0.25	7-16.4
7-15.5	2.3	19.0	86.5	25.0	154.4	28.5	0.75	7-16.6
7-15.8	1.9	19.9	86.9	13.8	158.8	31.8	1.25	7-16.8
7-17.6	3.9	19.9	86.9	16.3	127.5	32.0	0.75	7-19.8
7-14.4	1.2	18.5	85.1	13.8	148.3	23.5	1.25	7-15.2
7-15.1	1.2	18.5	86.0	28.8	167.6	27.0	0.00	7-15.8
7-14.3	1.3	17.9	86.2	43.8	157.5	31.8	0.25	7-15.0
7-14.8	1.4	18.1	86.5	47.5	162.9	34.8	0.25	7-15.6
7-16.4	2.4	18.1	86.3	30.0	139.2	35.0	2.00	7-17.8
7-20.5	1.8	17.9	84.8	11.3	151.8	24.5	0.75	7-21.5
7-20.8	2.4	17.0	83.6	20.0	160.1	24.5	0.25	7-22.0
7-21.3	3.3	15.9	83.6	38.8	147.0	29.0	0.00	7-23.4
7-22.6	4.6	16.0	83.4	32.5	140.0	30.8	1.50	7-25.5
7-23.2	4.1	15.4	82.1	55.0	125.5	33.3	1.25	7-25.8
7-19.2	2.1	15.3	84.6	16.3	149.6	23.3	1.50	7-20.6
7-20.1	1.8	14.9	83.5	40.0	147.5	27.3	0.75	7-21.0
7-20.6	2.8	14.7	82.5	41.3	140.6	29.8	1.25	7-22.5
7-20.5	3.0	14.6	83.1	52.5	140.0	32.5	0.75	7-21.6
7-23.4	5.3	16.9	82.8	52.5	123.6	33.0	2.25	7-26.4

Table 63. (Continued)

Hybrid	Cyto-plasm	Plants desired /plot	Har-vest plants /plot	Grain yield (bu/a)	Barren %	Ear wt. grams/ ear	Wt/ 100 seed grams	LAI	Grain /L.A. gm/ dm^2
A619 x A632	F	21	20.8	159.0	2.4	206	31.1	2.54	3.93
		27	28.0	176.8	6.2	190	30.5	3.49	3.17
		34	32.0	167.6	7.9	162	28.2	4.10	2.56
		41	38.5	160.7	18.0	146	28.6	4.85	2.10
		62	55.3	159.8	28.9	116	28.7	6.56	1.53
	S	21	21.5	166.4	2.3	184	31.2	2.27	4.59
		27	26.3	169.1	4.7	186	29.6	3.34	3.20
		34	34.3	175.5	3.6	152	27.8	4.22	2.60
		41	39.5	183.1	6.3	141	29.9	4.53	2.55
		62	53.0	163.8	21.2	112	26.2	6.36	1.61
P3510	F	21	21.0	156.5	15.3	216	26.3	3.05	3.23
		27	28.3	179.1	6.8	187	24.6	3.81	2.95
		34	34.0	162.7	6.5	148	24.6	4.79	2.15
		41	39.0	140.3	21.8	132	25.0	5.57	1.58
		62	53.8	143.2	35.9	119	25.4	7.44	1.22
	S	21	21.8	161.7	0.0	205	23.8	2.89	3.52
		27	29.0	168.2	5.1	175	23.6	3.98	2.65
		34	33.5	166.7	7.4	154	23.6	4.49	2.33
		41	38.0	169.4	9.2	140	23.8	5.35	1.99
		62	55.8	138.4	29.6	102	24.7	7.15	1.22

50% silk-ing (date)	Silking rate (days)	Harvest moisture %	% shelling	Lodging %	Combine yield (bu/a)	Number of ears /plot	Nubbins	75% silking (date)
7-14.3	0.9	17.1	86.7	35.0	160.7	22.0	0.00	7-14.7
7-14.2	1.2	16.7	86.2	43.8	165.8	26.5	0.25	7-14.8
7-14.6	1.4	17.4	86.7	71.3	162.3	29.5	1.25	7-15.5
7-15.5	4.1	16.9	86.6	57.5	157.9	31.5	1.50	7-18.4
7-16.5	1.8	17.3	86.6	52.5	147.1	39.3	1.50	7-17.6
7-13.9	1.3	16.8	86.6	38.8	157.8	25.8	0.25	7-14.8
7-13.3	1.1	16.7	86.2	58.8	165.5	26.0	0.25	7-13.9
7-13.8	0.9	16.6	86.2	76.3	170.9	33.0	0.00	7-14.3
7-14.4	1.2	16.2	86.4	72.5	161.6	37.0	0.25	7-15.2
7-15.6	2.3	16.0	86.8	82.5	150.4	41.8	1.25	7-16.9
7-19.5	2.1	20.7	86.0	30.0	152.0	21.0	2.25	7-20.7
7-20.0	2.6	19.6	86.8	47.5	169.7	27.3	0.25	7-21.5
7-19.7	2.8	20.0	85.8	62.5	163.5	31.8	0.00	7-21.3
7-21.8	2.9	20.1	85.5	40.0	159.8	30.5	2.25	7-23.5
7-22.4	6.6	19.9	86.2	35.0	135.3	34.3	2.25	7-27.4
7-18.1	1.5	19.4	86.4	55.0	154.9	22.5	0.00	7-18.9
7-18.5	2.0	19.9	86.2	57.5	166.2	27.5	0.00	7-19.8
7-19.5	2.1	19.5	86.1	70.0	161.9	31.0	0.00	7-20.6
7-19.4	2.4	19.4	86.8	77.5	157.7	34.5	0.00	7-20.9
7-21.6	4.6	19.5	86.1	51.3	148.0	39.3	0.75	7-24.8

Table 64. Plant characteristics and the mean squares for the response of 5 hybrids to 5 population levels in 1969

Source	d.f.	Grain yield	Combine yield	% barrens	Ear weight	Kernel weight
Blocks	3	54	286**	32	206	7.7
Hybrids (H)	4	4325**	1953**	326**	1063**	111.4**
Error (a)	12	102	73	18	96	2.2
Population (P)	4	4472**	3561**	4828**	53055**	66.2**
Cytoplasm (C)	1	3299**	316**	1463**	68	25.3**
P x C	4	354	150	20	136	0.2
Linear	1	4	333	53	248	0.5
Quadratic	1	950*	10	8	139	0.2
H x P	16	420**	178**	49	169*	5.5**
H x C	4	312	219	24	353*	7.3**
Linear	1	467	234	12	924**	2.9
Quadratic	1	5	306	6	3	0.0
H x P x C	16	228	51	48	197*	1.8
Error (b)	135	191	94	40	98	1.5
Coefficient of variation (%)		8.6	6.3	45.1	6.2	4.5

*Statistical significance at the 5% level of probability or greater.

**Statistical significance at the 1% level of probability or greater.

Table 64. (Continued)

Source	d.f.	Ears/ plot	% moisture	% shelling	% lodging	Plants /plot	Nubbins
Blocks	3	8.2	0.08	5.18**	920	4.8	0.87
Hybrids (H)	4	45.7**	106.31**	86.23**	8090**	19.7*	1.49
Error (a)	12	3.9	2.78	0.63	366	4.7	1.21
Population (P)	4	1269.6**	2.71**	1.18	6458**	6543.4**	7.57**
Cytoplasm (C)	1	200.0**	29.79**	0.44	6786**	0.2	3.64**
P x C	4	11.2	1.93	0.47	852**	4.7	2.21*
Linear	1	39.2*	3.2*	1.27	278		
Quadratic	1	3.4	0.1	0.02	959*		
H x P	16	26.4**	0.47	1.96**	530**	11.1**	0.95
H x C	4	6.3	3.21**	0.79	674*	0.9	4.41**
Linear	1	0.3	0.09	0.49	1406*		
Quadratic	1	1.6	6.86**	3.17	126		
H x P x C	16	9.0	1.48	0.64	186	4.7	1.20
Error (b)	135	7.6	0.77	0.87	218	4.9	0.77
Coefficient of variation (%)		9.2	4.9	1.1	33.2	6.2	118.7

Table 64. (Continued)

Source	d.f.	LAI	Grain /L.A.	Mid-silk date	Silking rate	75% silking
Blocks	3	0.38	0.042	3.1*	2.46	7.2
Hybrids (H)	4	9.14**	3.765**	327.9**	17.24**	428.7**
Error (a)	12	0.15	0.011	0.5	1.92	2.7
Population (P)	4	102.41**	31.968**	57.5**	32.25**	125.8**
Cytoplasm (C)	1	0.87*	1.558**	32.8**	16.97**	73.2**
P x C	4	0.04	0.063	0.8	1.37	3.3
Linear	1	0.11	0.061	0.0	0.19	1.1
Quadratic	1	0.01	0.000	1.0	4.02	6.2
H x P	16	0.14	0.214**	1.1	2.28*	3.6*
H x C	4	0.21	0.103	1.3	0.59	2.0
Linear	1	0.31	0.038	4.0*	1.00	7.3*
Quadratic	1	0.43	0.095	0.0	1.60	0.1
H x P x C	16	0.11	0.132	0.7	1.62	1.9
Error (b)	135	0.14	0.072	0.7	1.23	1.9
Coefficient of variation (%)		8.0	11.1	4.8	46.3	7.1

Table 65. Plant characteristics and the mean squares for the response of 4 hybrids with the fertile and sterile counterparts of each to 3 population levels, Beach, 1969

Source	d.f.	Grain yield	% barrens	75% silking date	Silking rate
Blocks	2	306.9*	64.0	0.76	0.10
Hybrids (H)	3	4487.4**	678.1**	152.58**	0.61
Error (a)	6	44.5	17.6	3.09	1.88
Population (P)	2	4008.1**	4354.4**	208.76**	43.97**
Cytoplasm (C)	1	1362.4**	1438.0**	134.76**	55.12**
P x C	2	834.2**	488.4**	19.26**	12.07**
H x P	6	705.1**	356.5**	6.58**	2.05
H x C	3	362.4**	170.7**	10.63**	5.01**
H x P x C	6	112.4	49.2	5.97*	2.59*
Error (b)	40	66.2	24.8	1.94	1.03
Coefficient of variation (%)		7.5	5.7	2.8	34.4

*Statistical significance at the 5% level of probability or greater.

**Statistical significance at the 1% level of probability or greater.

Table 66. Plant characteristics and response of 2 hybrids to row spacing, population level, and male-sterility in 1968

Row spacing	Hybrid	Cyto-plasm	Pop. plants/a 1000's	Combine yield (bu/a)	% barrens	Wt/100 seed (grams)	75% silking date	Silking rate (days)	% lodging
10"	SX 29	F	15	120	0.0	27.8	7-25.0	3.3	5
			30	108	24.5	25.2	8-29.0	8.0	5
			45	75	46.0	24.9	8-2.8	6.0	8
		S	15	137	2.5	28.4	7-24.3	2.0	8
			30	110	9.0	22.7	7-26.0	2.5	18
			45	97	16.0	24.2	7-28.8	4.3	8
	XL-45	F	15	114	0.0	26.8	7-17.5	2.0	8
			30	110	6.0	24.8	7-19.5	2.3	28
			45	103	16.0	25.4	7-22.0	9.3	23
		S	15	118	0.0	25.8	7-18.5	2.0	8
			30	135	7.0	24.0	7-19.8	3.3	38
			45	114	17.5	24.3	7-20.5	3.0	28
20"	SX 29	F	15	121	0.0	28.7	7-26.3	2.3	3
			30	98	15.5	23.5	8-1.3	7.8	8
			45	70	51.0	24.3	8-3.3	5.8	10
		S	15	132	0.0	28.0	7-25.3	2.8	0
			30	120	16.5	24.4	7-27.3	3.8	20
			45	87	16.5	22.6	7-29.0	4.0	13
	XL-45	F	15	124	0.0	26.4	7-17.5	2.0	8
			30	124	6.0	23.9	7-19.8	4.0	45
			45	104	17.0	23.0	7-21.3	5.8	40
		S	15	124	0.0	26.7	7-17.5	2.0	8
			30	132	3.0	23.7	7-18.8	2.3	13
			45	106	23.0	23.2	7-20.8	3.3	35

Table 66. (Continued)

Row spacing	Hybrid	Cyto-plasm	Pop. plants/a 1000's	Combine yield (bu/a)	% barrens	Wt/100 seed (grams)	75% silking date	Silking rate (days)	% lodging
30"	SX 29	F	15	122	2.0	27.8	7-26.0	2.3	15
			30	106	11.5	24.6	7-29.0	4.5	13
			45	71	40.5	24.1	8-2.0	6.8	25
		S	15	130	2.5	26.8	7-25.0	2.3	10
			30	118	15.5	23.9	7-27.8	4.5	25
			45	97	19.0	24.5	7-30.0	7.0	13
	XL-45	F	15	112	0.0	26.1	7-17.5	2.0	8
			30	119	10.5	25.2	7-19.5	3.0	10
			45	113	24.0	27.7	7-20.8	4.8	28
		S	15	140	0.0	25.2	7-17.5	2.0	13
			30	138	8.5	24.0	7-18.5	2.5	30
			45	111	26.5	23.6	7-23.3	6.5	45
40"	SX 29	F	15	127	0.0	27.2	7-25.8	2.5	0
			30	100	22.0	24.7	7-29.5	6.5	10
			45	76	40.5	24.6	8-2.3	8.5	5
		S	15	132	0.0	27.8	7-24.8	1.8	3
			30	121	13.5	24.4	7-28.3	3.8	8
			45	90	25.5	24.0	8-30.3	6.5	13
	XL-45	F	15	126	0.0	27.1	7-18.0	1.5	8
			30	119	8.5	24.0	7-20.5	3.8	15
			45	112	25.0	24.7	7-21.5	6.0	10
		S	15	119	1.5	25.5	7-18.3	2.5	8
			30	125	6.0	24.2	7-18.5	2.8	35
			45	111	25.0	24.7	7-21.5	5.3	33

Table 66. (Continued)

Row spacing	Hybrid	Cyto- plasm	Pop. plants/a 1000's	Combine yield (bu/a)	% barrens	Wt/100 seed (grams)	75% silking date	Silking rate (days)	% lodging
60"	SX 29	F	15	122	7.0	26.0	7-27.0	3.8	5
			30	99	13.0	25.3	7-28.0	4.0	15
			45	64	49.5	24.0	8-2.0	9.3	20
		S	15	114	0.0	27.2	7-26.3	1.8	3
			30	108	20.5	24.0	7-27.0	3.8	25
			45	77	34.0	23.0	7-29.5	6.5	8
	XL-45	F	15	105	0.0	26.8	7-17.8	2.5	0
			30	91	10.5	25.4	7-20.5	3.0	25
			45	91	22.0	24.9	7-23.0	4.8	28
		S	15	100	0.0	25.8	7-22.8	2.8	5
			30	108	10.0	23.3	7-21.0	4.8	28
			45	91	29.5	23.5	7-21.3	6.5	65

Table 67. Plant characteristics and the mean squares for the response of 2 hybrids to row spacing, population, and male-sterility in 1968

Source	d.f.	Grain yield	Percent barrens	Silking date	Silking rate	Kernel weight
Blocks	1	1540.8	381.6^{*}	0.0	0.00	1.1
Row spacing (R)	4	1142.9	69.5	3.5	0.35	1.0
Error (a)	4	260.2	28.4	1.6	0.06	0.9
Hybrids (H)	1	2822.7^{**}	1484.0^{**}	2244.7^{**}	12.35^{*}	4.0
R x H	4	211.6	30.2	4.8	0.40	0.5
Error (b)	5	55.0	18.9	1.1	0.30	2.0
Cytoplasm (C)	1	2940.3^{**}	$480\ 0^{**}$	38.5^{**}	8.27^{**}	12.5^{**}
Population (P)	2	9003.7^{**}	7612.3^{**}	213.3^{**}	16.64^{**}	95.4^{**}
C x P	2	207.3	267.5^{*}	13.8^{**}	1.14	0.7
R x C	4	130.7	26.1	3.2	0.47	0.9
R x P	8	28.3	25.4	2.0	0.62	1.9
R x C x P	8	49.0	30.1	2.1	6.50	0.7
H x C	1	240.8	691.2^{**}	46.9^{**}	3.87^{**}	1.1
H x P	2	2699.4^{**}	269.8^{*}	17.3^{**}	1.89^{*}	7.5^{**}
H x C x P	2	221.3	554.7^{**}	2.9	0.13	0.7
R x H X C	4	78.9	23.0	1.0	0.59	0.7
R x H x P	8	30.4	21.4	0.8	0.55	0.5
R x H x C x P	8	88.1	41.2	2.0	0.37	1.1
Error (c)	50	77.6	54.4	1.8	0.53	1.2
Coefficient of variation (%)		8.0	54.3	5.6	17.7	4.3

*Statistical significance at the 5% level or greater.

**Statistical significance at the 1% level or greater.

Table 68. Analyses of variance for total and ear height light flux intercepted and ear height for variety SX 29

Source	d.f.	Total interception	Ear height interception	Ear height
Blocks	1	0.1	14.0	0.8
Row spacing (R)	4	950.6**	1223.9**	21.7
Error (a)	4	5.3	12.4	4.1
Cytoplasm (C)	1	1.3	6.0	6.0
Population (P)	2	347.5**	1706.1**	6.7
C x P	2	16.8	96.0	0.5
R x C	4	32.8	169.7**	5.3
R x P	8	20.0	55.3	8.6*
R x C x P	8	30.6	73.3	2.9
Error (b)	25	19.5	34.3	3.1
Coefficient of variation (%)		42.0	22.6	3.0

*Statistical significance at the 5% level.

**Statistical significance at the 1% level.

Table 69. Plant characteristic and the mean response for 10 hybrids planted at 2 row spacings, 2 populations and for the 2 types of cytoplasm in 1968

Hybrids	Row spacing	Cyto-plasm	Plants /plot	Grain yield (bu/a)	Ears/ 100 stalks	75% silking date	Silking rate (days)	Kernel weight (grams)	Ear weight (grams)
A619 x A632	20"	F	14.5	140.3	101.8	7-17.6	1.6	29.3	200
			33.8	121.8	69.3	8-1.5	14.3	27.7	109
		S	15.5	158.5	105.5	7-17.6	1.4	27.9	207
			34.3	137.0	74.0	7-23.5	6.8	28.0	114
	40"	F	14.0	150.0	100.0	7-17.9	1.6	28.8	225
			29.8	127.0	75.5	7-22.2	5.5	27.3	115
		S	13.5	146.5	122.3	7-17.5	1.6	27.5	187
			37.5	144.8	79.5	7-21.5	4.5	27.5	103
UH 138	20"	F	16.3	131.8	91.5	7-19.8	2.6	25.3	188
			36.3	145.3	68.0	8-3.4	11.3	23.2	102
		S	14.8	115.8	95.3	7-18.8	1.8	24.1	219
			33.0	132.5	75.5	7-26.1	6.3	23.8	107
	40"	F	15.0	131.8	98.0	7-20.9	3.1	24.6	189
			34.5	117.0	68.0	7-29.8	8.4	23.6	105
		S	13.8	144.8	96.5	7-19.8	2.0	25.2	231
			31.5	143.0	80.3	7-23.4	3.5	23.6	122
P3510	20"	F	15.8	123.3	75.8	7-23.9	2.5	28.3	217
			32.8	83.3	45.8	8-6.9	12.5	27.7	120
		S	15.5	170.0	100.5	7-22.4	2.6	27.0	231
			34.0	123.8	63.8	8-6.3	13.8	27.0	120
	40"	F	14.8	143.3	87.3	7-24.4	2.6	28.8	237
			33.5	89.5	51.8	8-3.8	9.4	28.1	111
		S	15.8	164.5	98.5	7-23.0	2.5	27.5	224
			35.0	136.0	73.5	7-29.5	7.1	28.1	112
336 x 025	20"	F	16.0	110.0	94.0	7-19.0	1.9	23.4	155
			35.5	95.8	70.0	7-22.3	4.3	20.2	82

Table 69. (Continued)

Hybrids	Row spacing	Cyto-plasm	Plants /plot	Grain yield (bu/a)	Ears/ 100 stalks	75% silking date	Silking rate (days)	Kernel weight (grams)	Ear weight (grams)
		S	15.3	113.5	101.8	7-19.1	2.1	22.0	152
			33.3	99.3	71.5	7-21.4	3.1	22.2	88
	40"	F	13.8	112.8	98.0	7-18.6	1.6	23.0	176
			37.0	90.0	67.8	7-22.4	4.0	20.9	76
		S	14.3	113.5	103.8	7-19.0	1.9	22.3	162
			31.3	109.8	83.0	7-21.1	2.8	20.2	89
P3306	20"	F	15.5	164.0	98.5	7-23.4	1.6	32.7	226
			33.0	119.5	66.0	8-2.1	7.9	30.2	120
		S	14.5	167.8	98.5	7-23.8	2.3	32.0	249
			37.3	138.5	71.0	7-29.4	6.3	31.7	111
	40"	F	13.5	162.8	106.8	7-25.6	3.1	31.8	241
			33.8	141.3	71.3	8-3.2	7.8	31.8	124
		S	14.8	173.3	98.5	7-24.6	2.9	32.3	251
			36.5	135.0	72.8	7-31.0	6.1	32.2	107
B14 x 577	20"	F	15.2	142.0	109.8	7-23.8	2.6	29.8	179
			38.8	121.8	58.5	8-4.3	13.0	27.5	114
		S	16.2	147.8	112.8	7-22.5	1.9	29.3	172
			36.0	125.8	75.3	7-29.8	7.3	25.8	99
	40"	F	13.0	144.0	133.3	7-24.8	2.8	29.0	176
			34.5	118.8	73.8	7-27.8	5.1	26.3	100
		S	12.8	149.3	140.3	7-23.3	2.5	27.9	178
			36.0	126.8	78.3	7-26.0	3.5	27.0	96
336 x 029	20"	F	15.8	125.3	99.0	7-18.5	1.9	24.7	170
			34.5	118.5	76.3	7-27.6	9.9	20.4	96
		S	14.8	137.5	120.3	7-18.5	1.9	24.7	164
			34.8	109.0	75.5	7-21.0	4.0	18.7	88
	40"	F	14.3	124.5	103.8	7-18.9	2.1	23.1	178
			34.0	117.8	76.8	7-20.4	2.9	19.4	95

Table 69. (Continued)

Hybrids	Row spacing	Cyto-plasm	Plants /plot	Grain yield (bu/a)	Ears/ 100 stalks	75% silking date	Silking rate (days)	Kernel weight (grams)	Ear weight (grams)
		S	15.5	123.8	113.0	7-19.3	2.5	22.8	149
			36.3	117.3	81.8	7-20.6	3.6	18.0	84
SX 29	20"	F	15.3	121.3	96.8	7-24.5	2.0	27.9	176
			28.8	62.5	56.8	8-5.1	10.6	24.3	82
		S	15.5	135.8	95.5	7-23.6	1.4	27.5	195
			34.5	116.8	73.0	7-28.8	4.3	25.6	97
	40"	F	14.0	140.3	111.3	7-25.4	2.6	27.9	191
			26.5	83.3	69.8	8-2.0	6.8	24.4	97
		S	14.5	133.5	101.8	7-24.8	1.9	28.4	190
			34.5	94.3	68.0	7-29.9	5.3	24.7	85
PX610	20"	F	14.0	133.5	98.0	7-20.8	3.1	28.3	200
			31.5	114.5	70.3	7-26.1	5.6	27.1	102
		S	16.8	165.8	97.0	7-19.5	2.3	28.8	215
			36.0	141.3	79.3	7-24.5	4.5	28.2	105
	40"	F	14.3	139.0	102.0	7-21.6	3.3	28.5	202
			37.0	107.8	65.3	7-29.5	8.5	26.7	98
		S	13.8	147.5	101.5	7-21.0	2.9	29.8	234
			32.5	133.3	83.0	7-22.9	3.4	27.4	102
XL-45	20"	F	15.3	139.3	103.3	7-18.0	1.9	27.7	188
			39.8	118.5	61.0	8-2.3	13.6	26.0	107
		S	15.5	153.5	111.3	7-19.8	3.0	26.3	189
			40.5	136.0	76.5	7-23.8	6.0	24.3	94
	40"	F	15.3	139.0	98.5	7-20.1	2.9	27.0	196
			35.3	105.5	68.3	7-23.9	6.1	24.9	94
		S	14.8	141.3	107.3	7-18.6	1.8	26.2	189
			32.0	141.3	85.0	7-21.0	3.4	23.4	112

Table 70. Plant characteristic and the mean squares for the response of 10 hybrids to row spacings, population, and male-sterility in 1968

Source	d.f.	Grain yield	Ears/100 stalks	75% silking	Silking rate	Kernel weight	Ear weight
Blocks	3	474	73	23.9	15.4	0.9	538
Hybrids (H)	9	5785**	1233**	364.1**	32.6**	327.9**	10360**
Error (a)	27	198	68	8.5	8.2	2.1	207
Row spacing (R)	1	109	2237**	100.7**	132.6**	2.4	291
H x R	9	173	180*	20.9*	4.0	2.6	117
Error (b)	30	256	71	8.0	6.3	1.7	224
Population (P)	1	44204**	81728**	3514.5**	1660.8**	292.6**	724150**
Cytoplasm (C)	1	17214**	4651**	452.4**	222.8**	7.6**	127
P x C	1	1221*	289*	267.4**	163.9**	3.4	324
H x P	9	1159**	537**	49.1**	26.8**	14.6**	2398**
H x C	9	974**	238**	8.0	7.1	4.0**	890**
H x P x C	9	230	153**	6.2	3.9	1.5	500*
R x P	1	116	19	269.2**	201.6**	0.3	875*
R x C	1	705	24	16.9	15.3	1.4	638
R x P x C	1	602	42	33.5*	23.1*	1.4	802*
H x R x P	9	69	113	15.8**	11.1*	1.4	87
H x R x C	9	266	87	9.3	7.9	0.2	457*
H x R x P X C	9	237	94	13.4*	8.4	1.4	114
Error (c)	180	218	69	5.9	5.3	1.1	215
Coefficient of variation (%)		11.4	9.5	9.9	51.0	4.0	9.8

*Statistical significance at the 5% level or greater.

**Statistical significance at the 1% level or greater.

Table 71. Plant characteristics and the mean response of 2 hybrids to 3 row spacings, 5 population levels, and cytoplasm type in 1969

Row spacing	Hybrid	Cyto-plasm	Pop[1]	Grain yield (bu/a)	Ears/ 100 stalks	75% silking date	Silking rate (days)	Ear weight (grams)
10"	SX 29	F	1	135.7	109	7-25.6	1.1	211
			2	136.7	89	7-27.3	2.4	173
			3	137.9	85	7-28.9	3.3	139
			4	118.3	76	8-0.4	4.3	105
			5	117.6	65	7-30.6	4.8	102
		S	1	146.0	120	7-26.0	1.2	208
			2	145.3	91	7-30.3	5.7	180
			3	138.4	84	7-28.5	3.2	141
			4	122.2	80	8-0.5	4.6	104
			5	124.2	65	7-30.6	3.6	107
10"	P3306	F	1	149.5	103	7-28.3	2.5	246
			2	159.7	93	7-28.3	2.4	193
			3	150.4	85	7-30.4	3.6	150
			4	137.2	73	8-0.3	3.5	127
			5	158.0	66	8-1.7	3.1	135
		S	1	134.0	105	7-26.4	1.8	216
			2	140.6	94	7-28.8	2.8	169
			3	160.0	92	7-29.3	2.6	147
			4	146.5	76	8-0.3	4.6	129
			5	132.0	68	8-0.7	3.8	113
20"	SX 29	F	1	119.5	113	8-1.1	7.1	180
			2	141.8	95	7-28.9	5.4	168
			3	133.5	78	7-28.8	3.4	144
			4	122.2	67	7-29.7	3.1	126
			5	126.6	64	7-30.1	3.3	111
		S	1	127.6	128	8-1.1	6.1	172
			2	146.5	99	8-3.5	9.0	168
			3	158.5	80	7-30.4	5.1	167
			4	131.8	68	8-4.3	9.8	131
			5	139.6	73	7-30.0	3.3	109

[1]Plant population in plants/a: 1 = 15,000, 2 = 22,500, 3 = 30,000, 4 = 37,500, 5 = 45,000.

Table 71. (Continued)

Row spacing	Hybrid	Cyto- plasm	Pop[1]	Grain yield (bu/a)	Ears/ 100 stalks	75% silking date	Silking rate (days)	Ear weight (grams)
20"	P3306	F	1	162.9	112	7-27.9	2.3	247
			2	181.8	99	7-28.8	2.2	208
			3	188.5	91	7-30.0	2.7	175
			4	154.1	81	8-2.4	4.7	131
			5	153.1	72	8-1.5	4.7	121
		S	1	144.8	106	7-27.8	2.3	231
			2	160.5	94	7-28.8	3.2	192
			3	159.8	93	7-30.4	2.7	145
			4	129.8	74	8-2.1	4.8	118
			5	122.7	65	8-1.8	4.1	109
40"	SX 29	F	1	148.9	123	7-28.8	3.3	207
			2	161.2	95	7-28.7	3.4	191
			3	151.4	90	7-30.3	4.3	143
			4	131.3	76	8-1.8	5.8	116
			5	121.3	72	8-2.6	4.8	96
		S	1	156.8	120	7-28.8	2.4	222
			2	172.0	100	7-28.0	2.4	194
			3	159.0	94	7-29.8	2.3	143
			4	143.3	88	8-1.4	4.7	110
			5	137.2	82	8-1.4	4.1	95
40"	P3306	F	1	162.2	113	7-29.5	2.7	244
			2	184.3	98	7-30.7	2.8	212
			3	179.2	89	8-1.7	3.0	171
			4	159.3	77	8-2.8	4.1	141
			5	149.2	68	8-4.6	3.6	124
		S	1	150.2	106	7-29.2	2.6	240
			2	176.0	97	7-29.7	2.8	205
			3	175.2	93	8-0.8	3.3	159
			4	153.4	86	8-1.9	3.6	120
			5	131.8	67	8-4.6	3.9	110

Table 72. Plant characteristic and the mean squares for the response of 2 hybrids in 40-inch row spacing to 5 population levels and male-sterility in 1969

Source	d.f.	Grain yield	Ears/100 stalks	Ear weight	75% silking	Silking rate
Blocks	2	412.8	24.8	138	1.46	3.01
Hybrids (H)	1	2871.8	299.0	6531*	37.20	4.13
Error (a)	2	653.5	120.4	95	8.60	0.65
Population (P)	4	2808.8**	3177.7**	31993**	62.80**	7.47**
Cytoplasm (C)	1	6.7	160.6*	309	5.25	5.25*
P x C	4	12.8	94.7*	15	0.17	0.27
H x P	4	157.4	90.9*	60	2.39	0.88
H x C	1	1555.5**	82.4	680**	0.01	4.96*
H x P x C	4	47.7	13.2	8	0.35	0.34
Error (b)	36	82.0	31.7	144	1.44	0.72
Coefficient of variation (%)		5.8	6.2	7.5	3.8	24.5

*Statistical significance at the 5% level or greater.

**Statistical significance at the 1% level or greater.